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Edited by

O. M. B. BULMAN and S. R. NOCKOLDS

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CONTENTS

PAGE

BLACK, GEORGE P. The Acid Rocks of Western Rhum 257

HOSKING, K. F. G. The Pegmatites of Trolvis Quarry, Carnmenellis, Cornwall 273

SADASHIVAIAH, M. S. The Granite-Diorite Complex of the Insch Igneous Mass, Aberdeenshire 286

WELLS, M. K. The Structure of the Granophyric Quartz-Dolerite Intrusion of Centre 2, Ardnamurchan and the Problem of Net-Veining 293

PITCHER, W. S., D. J. SHEARMAN,, and D. C. PUGH. The Loess of Pegwell Bay, Kent, and its Associated Frost Soils 308

TEMPLE, J. T. The Hypostome of *Encrinurus variolaris* and its Relation to the Cephalon 315

COPE, R. N. Cyrtograptids and Retiolitids from County Tipperary . 319

CORRESPONDENCE

Rules of Nomenclature 325

The Caribbean "Oligocene" 326

REVIEWS

pp. 327–336

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GEOLOGICAL MAGAZINE

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The Acid Rocks of Western Rhum

By GEORGE P. BLACK

ABSTRACT

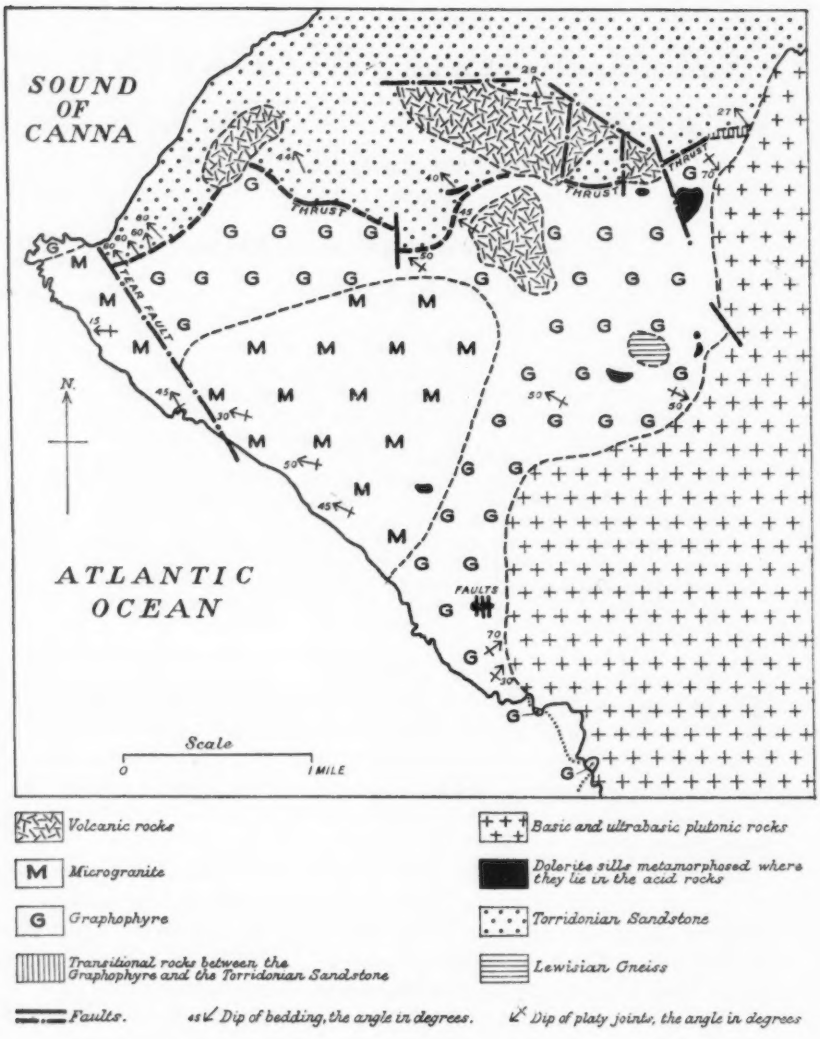
In the west of the Isle of Rhum (Inverness-shire), Tertiary acid rocks outcrop over an area of approximately 6 square miles. A core of spherulitic microgranite is surrounded by graphophyre [1] which, in turn, is bounded on the north by Torridonian Sandstone; although much of the boundary is marked by a low-angle reverse fault, part of the junction is undisturbed and a belt of transitional rocks, some 1,400 feet in width, intervenes between the graphophyre and the Torridonian Sandstone. The transitional rocks are divisible into five zones which are interpreted as marking successive stages in the conversion of sandstone into graphophyre. Evidence is presented indicating that the microgranite, into which the graphophyre grades inwards, represents a still more advanced stage of transformation.

1. INTRODUCTION

IN the west of Rhum, Tertiary acid rocks outcrop over a roughly triangular area of some 6 square miles. They have hitherto been considered as a single petrological unit, designated granophyre, but the writer has been able to distinguish, and map separately, a graphophyre towards the north and east and a spherulitic microgranite in the south-west.

The graphophyre is bounded on the north by Torridonian Sandstone, on the east by other members of the Tertiary complex of Rhum, and, wherever the boundary is exposed, on the south and west by the microgranite. Unconformable outliers of Tertiary volcanic rocks partly cover the graphophyre in the north (Black, 1952, *a* and *b*), and several small lenticles of basic rocks are included in and metamorphosed by the acid rocks. These lenticles show a close petrographic resemblance to lenticular sills found in the near-by Torridonian rocks to the north. A patch of " gneiss " is mapped within the tract of the acid rocks; it is so broken up by weathering that its relations cannot be determined; it is even uncertain whether it is *in situ* or not.

[1] The term " graphophyre " is used in preference to " granophyre " to describe one type of the acid rocks, since the latter term has been usedi n many previous publications as descriptive of the acid rocks as a whole.



TEXT-FIG. 1.—Geological map of the western part of the Isle of Rhum.

Although descriptions of the acid rocks and of the Torridonian were given by Macculloch (1819, i, 487), Judd (1874, 252–3), and Geikie (1897, ii, 409), the first description of the contact between them was supplied by Harker (1908, 5–7, 102–5), who concluded that " on the whole the granite overlies the sandstone ". He further recorded a

considerable increase in the dip of the sandstones on approaching the contact and a decrease in the dip of the contact as it was traced from east to west. He postulated that the acid rocks formed a laccolith intruded into the sandstone or between the sandstone and the lavas above. Bailey did not examine the acid rocks in the field but surmised (1944, 184) that they constitute " the filling of a subterranean cauldron-subsidence ".

The writer has demonstrated that the lavas of Orval are unconformable on the underlying graphophyre (Black, 1952, *a*), thus confirming Judd's conjecture (1874, 254) of nearly eighty years ago. In the present study special attention is given to the internal structure of the acid mass and to its contact relations with the Torridonian.

2. Field Relations

The country rocks, with which the acid rocks are in contact at the present surface of erosion, are red feldspathic sandstones and pebbly grits belonging to the Torridonian. They dip at approximately 30° towards the north-west and are not well exposed except in sea-cliffs.

The graphophyre is a highly leucocratic drusy rock with plagioclase phenocrysts and small, sparsely distributed clots of ferromagnesian minerals. A series of platy joints with dips to the north-west at angles between 30° and 50° is intersected at right-angles by two or more series of columnar joints. As the platy joints are by far the most prominent, the rock has a bedded aspect. In the microgranite, which is of finer grain, the columnar joints are more prominent than the platy joints and the rock is decidedly columnar in appearance, a fact first noted by Macculloch (1819, i, 487). The transition from graphophyre to microgranite is effected by a gradual reduction in granularity.

The relationship between the graphophyre and the Torridonian Sandstone is more complex. The contact is poorly exposed and trends approximately east and west for 4¾ miles; it falls naturally into two portions. For some 4½ miles from its western (seaward) extremity it is a low-angle reverse fault which separates typical graphophyre from unmetamorphosed Torridonian Sandstone to the north; any aureole that may have surrounded the graphophyre has been faulted out. The fault-plane dips southwards at 30° in the extreme west but the angle of dip increases eastwards until where the fault is last seen the angle of dip is over 80°. Further east the dislocation appears to die out gradually. With increased dip of the dislocation, its effect on the dip of the Torridonian Sandstone decreases. In the extreme west the sandstones and grits have been highly disturbed; near the dislocation their dip has been increased from the regional value of 30° to almost 70° and their strike is almost due east and west. In the east, however,

the Torridonian strata dip to the north-west at angles very close to the regional dip.

Wherever the fault is exposed normal graphophyre is seen to be separated from the Torridonian by a belt of milled rocks some 10 feet in thickness. Thin-sections show that the graphophyre near the fault is traversed by narrow shatter zones of comminuted graphophyric material, the proportion of which gradually increases as the fault is approached, until a rock is encountered which contains fragments of quartz and micropegmatite embedded in a more finely ground matrix which has the appearance of devitrified glass. Eventually the proportion of porphyroclastic fragments decreases and some have been partly fused peripherally; the rock is a typical mylonite. When traced towards the fault the Torridonian is seen to have likewise given rise to a mylonite consisting of small quartz fragments set in a very finely ground or devitrified matrix.

It is clear that the reverse fault operated after the emplacement of the graphophyre, which it mills, but before the eruption of the lavas, which are unaffected by it.

The eastern part of the contact is only some 400 to 500 yards in length; here no faulting has occurred and the Torridonian Sandstone grades imperceptibly into the graphophyre through an intervening strip of transitional rocks. The contact here dips at approximately 80° towards the north and is not well exposed except in a somewhat broken scarp which forms the eastern face of the low hill of Minishal (*c.* 1,150 feet), some 3 miles west by north of Kinloch Castle. From a distance the cliff appears to consist of a succession of homogeneous beds with a slight apparent dip to the north. On closer examination of the cliff, however, it is seen that its southern part is made up of graphophyre and its northern part of Torridonian Sandstone, while the intervening part consists of transitional rocks. The bedding planes of the feldspathic sandstones and grits are continued by a series of prominent parting planes in the transitional rocks, which in turn are continued by the platy joints of the graphophyre. Moreover, the individual beds of sandstone and grit can be traced undisturbed across the transitional rocks into the corresponding " beds " of the graphophyre. The gradation from sandstone and grit into graphophyre is perfect. The southernmost sandstones occur some 1,400 feet from the northernmost outcrops of typical graphophyre and this figure is taken as the width of outcrop of the transitional rocks.

Field investigation of the transitional rocks shows that several different types can be discriminated but, since no sharp contacts have been found between the types, it is impossible to map them separately. However, the various types can be seen to form zones roughly parallel to the belt of transitional rocks as a whole.

3. Petrology

(*a*) *Torridonian Sandstone.*

The Torridonian rocks of the west of Rhum, outside the aureole of the acid rocks, resemble very closely those of Skye and of the mainland. Quartz is the most abundant mineral and occurs as poorly rounded detrital grains often with an undulose extinction. Feldspars, although present in a smaller proportion than quartz, are always present. The commonest feldspar is orthoclase; in addition microcline is often present and rare plagioclase also occurs. Kaolinization and chloritization have affected the feldspars slightly. Flakes of muscovite are sparsely distributed throughout the rocks and some detrital grains of magnetite are also present. Very occasionally there occur grains of other minerals but these make up probably less than 0·1 per cent of the rock. The cement, small in quantity and fairly evenly distributed, is largely haematite. Argillaceous impurities are normally present in the cement and on slight metamorphism give rise to a pale green chlorite. The grain of the sandstones ranges from 0·25 mm. to 0·75 mm.

(*b*) *Transitional Rocks between the Torridonian Sandstone and the Graphophyre.*

For convenience the transitional rocks have been divided into five parallel zones which are here lettered A to E successively from the Torridonian in the north to the graphophyre in the south. Modes of the transitional rocks could not be determined owing to their very variable composition over a single thin-section and to their fineness in grain.

Zone A.—The rocks of this zone are the bleached and indurated representatives of the Torridonian Sandstone immediately to the north. The rocks have a fracture like that of a quartzite and the dispersed haematite cement has been reduced and concentrated into irregular grains of magnetite thus causing the rock to become pale cream, a phenomenon first explained by Harker (1908, 13). The undulose extinction of the quartz grains, so prominent in the red sandstones, is now less conspicuous, and where quartz grains were separated one from another by small thicknesses of cement they are now immediately contiguous and commonly sutured together. This suturing together of the quartz grains probably accounts for the much greater hardness and the quartzitic fracture of the indurated rocks. A green or greenish-brown biotite, associated with small crystals of magnetite, has been produced from the argillaceous material. The zone is approximately 900 feet wide and consists of silicified Torridonian feldspathic sandstones and grits which have suffered slight metamorphism.

Zone B.—In Zone B, which is 80 feet wide, the Torridonian has been further altered. The detrital grains of " heavy minerals " and orthoclase are still preserved and the bedding is clearly traceable across the zone, but flakes of brown and highly pleochroic biotite are present and increase in amount southwards. Towards the south, sutured aggregates have been produced by the recrystallization of individual quartz grains and the undulose extinction, which is so typical of the clastic quartz grains in the unaltered Torridonian, is no longer found.

The orthoclase occurs not only as detrital grains but also as clear intergranular films which develop between the quartz grains and cement them together. These " veinlets " increase in amount towards the south of the zone until, near the southern margin, they form a matrix in which the quartz grains are embedded. In one or two cases a particularly large crystal of the new orthoclase encloses several quartz grains, normally oriented at random, but exceptionally sharing a common optical orientation and forming a very rudimentary intergrowth with the surrounding orthoclase. This clear orthoclase is easily distinguishable from the cloudy clastic grains of potash feldspar (the proportion of which remains unchanged), and its development and southward increase demonstrate that K and Al have been introduced from the south, apparently by migration along the intergranular boundaries.

Zone C.—Zone C is 20 feet in width. Alteration of the Torridonian is now profound but the bedding retains the same dip and strike as in the unaltered Torridonian. Some detrital grains of quartz and orthoclase still occur but, as in Zone B, the quartz no longer has an undulose extinction. Small new crystals of orthoclase, often in rudimentary intergrowth with quartz, occur in addition to the clastic orthoclase grains. Towards the south of the zone the rocks differ markedly from those of Zone B in that (*a*) the intergrowths are larger and better developed, (*b*) the clastic orthoclase becomes indistinguishable from the orthoclase newly formed by metasomatism, and (*c*) the total proporton of potash feldspar has appreciably increased.

Porphyroblasts of intensely pleochroic brown biotite occur throughout the zone and are often poikiloblastic. Equidimensional granular crystals of hypersthene and small grains of magnetite are everywhere present but are especially abundant near the biotite. The proportion of ferromagnesian minerals increases southwards and the maximum for all the rocks here considered is reached at the southern margin of the zone where the rocks have become mesotype. Moreover, the zone is characterized by an extraordinary abundance of apatite, a mineral very rare in the Torridonian. The proportion of apatite increases southwards to reach a maximum at about the middle of Zone C.

No Torridonian rocks are known having such compositions and there seems to be no escape from the conclusion that Fe, Mg, and P have been introduced and metasomatically fixed in the rocks of Zone C.

Zone D.—Zone D is 20 feet in width. The Torridonian bedding continues with unchanged dip and strike across the zone. In its northern part the rocks consist of a fine granular matrix of quartz, orthoclase, hypersthene, magnetite, and apatite containing poikilitic porphyroblasts of biotite and sparse small pods of quartz and orthoclase which contain accessory amounts of the other minerals of the rock.

The quartzo-feldspathic pods, which are characteristic of Zone D, contain porphyroblasts of orthoclase enclosing numerous quartz grains and are surrounded by a basified rim, the matrix of which has been enriched in biotite and hypersthene. The quartz grains enclosed in a single orthoclase porphyroblast, though often oriented at random, frequently share a common optical orientation and form a micrographic intergrowth with the host orthoclase. Towards the south the pods increase in abundance so that the matrix is reduced to interstitial clots and irregular marginal " veins ", while the proportion of intergrown orthoclase increases until, at the southern margin of the zone, where the intergrowths are large, well-developed, and free from inclusions, all the orthoclase is intergrown with quartz. The marked southward increase in abundance of the pods clearly indicates that K, Al, and Si have been introduced from the south. Moreover, the concomitant development of micrographic intergrowths in the pods shows that typical micrographic textures have been produced by metamorphic and metasomatic processes.

The proportion of the ferromagnesian minerals steadily decreases southwards across the zone. Biotite, which builds large poikiloblastic crystals in the north of the zone, occurs only as small compact flakes in the south. Hypersthene, present in considerable quantity in the north, dies out in the south of the zone, whereas hornblende, absent in the north, becomes the predominant ferromagnesian mineral in the south, where it makes up clumps of large, subhedral or anhedral crystals associated with much magnetite and some biotite.

Zone E.—The rocks of this zone, 350 feet wide, are largely made up of intergrowths of quartz and orthoclase, similar to those of both Zone D and the graphophyre. A few discrete crystals of quartz still persist. Green hornblende is the dominant ferromagnesian mineral and is associated with abundant magnetite. Some biotite persists in the north of the zone but becomes very rare in the south. Magnetite is common and there are occasional prisms of apatite. Hypersthene, which dies out towards the south of Zone D, has not been found in Zone E. The southward decrease in the total proportion of ferromagnesian minerals continues across Zone E, but the rate of decrease

is lower than in Zone D. As before, the Torridonian bedding continues undisturbed across the zone. The close resemblance of the rocks of Zone E to the metamorphosed Torridonian rocks of Zone D leads to the conclusion that the former are also the metamorphosed equivalents of the Torridonian sandstones and grits.

The essential new feature characterizing Zone E is the appearance of porphyroblasts of plagioclase for the first time in the sequence. These have a composition of An_{15},[1] are highly sericitized, and contain inclusions of quartz, hornblende, and magnetite. The porphyroblasts increase in size towards the south and also, to a lesser extent, in numbers, the rate of increase being most pronounced in the northern part of the zone. They are frequently fringed by areas of micropegmatite, the orthoclase of the latter being sometimes in optical continuity with the plagioclase of the porphyroblast. Also the quartz blebs included in the porphyroblasts frequently share a common optical orientation with the quartz of one of the neighbouring intergrowths. From this it appears that the porphyroblasts have replaced the orthoclase of the micropegmatite more easily than the quartz, relics of which remain incorporated as inclusions. The development of the plagioclase porphyroblasts demonstrates that Na and Ca have been added to the rocks of Zone E.

(*c*) *Graphophyre.*

The graphophyre is a medium-grained leucocratic rock consisting for the most part of quartz and orthoclase with subsidiary plagioclase, hornblende, and magnetite. Accessory minerals are rare but include apatite, pistacchio-green epidote, and muddy-brown biotite. Limonite, goethite, serpentine, and chlorite have developed as alteration products from hornblende, and kaolin from feldspar.

The graphophyre closely resembles the rocks of Zone E. The micrographic intergrowths of both rocks are identical, plagioclase porphyroblasts occur in both, and the interstitial clots of hornblende in the graphophyre differ from the clots of hornblende with a little biotite in Zone E only by the suppression of the latter mineral. This continuance of characters from the metasomatized Torridonian rocks of Zone E into the graphophyre leads to the conclusion that the graphophyre is itself a metamorphosed representative of the Torridonian Sandstone. Further evidence for this conclusion is furnished by (*a*) the continuance of the Torridonian bedding-planes by the platy joints found throughout the graphophyre; (*b*) the absence of any contact demarcating the graphophyre from the metamorphosed Torridonian rocks of the transitional zones; (*c*) the absence of any

[1] The plagioclase compositions recorded in this paper have been determined by the symmetrical extinction angle in Albite twins.

chilled marginal phase of the graphophyre; (*d*) the absence of any veins of graphophyre, and (*e*) the complete lack of xenoliths. It should be noted, however, that the presence of veins and xenoliths (skialiths) would not invalidate the conclusion reached.

Moderately coarse micrographic intergrowths of quartz and orthoclase make up at least 50 per cent of the graphophyre and in some specimens as much as 75 per cent. The proportions of quartz and orthoclase in the intergrowths vary considerably but the latter mineral is always the more abundant.

Although most of the quartz is intergrown with orthoclase, some discrete anhedral quartz crystals are also found. These crystals form small groups and occur between the units of intergrowth.

Plagioclase (An_{15-20}) forms repeatedly twinned, faintly zoned crystals which vary greatly in size and are subhedral or anhedral; the smaller crystals tend to give rhombic sections in thin slices, whereas the larger crystals are more frequently irregular and are often packed with inclusions. Where plagioclase is bounded by micropegmatite, indentations now occupied by intergrown quartz and orthoclase have been produced in the plagioclase, which has been attacked along cleavages and twin planes, one twin member being attacked in preference to its neighbours. As a result conspicuous rectangular indentations have been produced in certain parts of the crystals, and the boundaries of the plagioclase where they intercept cleavages or twin planes, have castellated margins; no rounding of the plagioclase crystals has been noticed. On boundaries, which are not so intersected, irregular indentations controlled by cracks have been produced. Where one of these indentations is deep enough to reach a cleavage or twin plane the margin of the indentation follows this for some distance before diverging and again becoming irregular.

The plagioclase crystals of Zone E are subhedral or euhedral and their margins are not indented in the above fashion, and since the graphophyre has been formed from rocks like these of Zone E, the indentations must be due to some process which has operated during the last stages of evolution of the graphophyre. The indentations result from a partial replacement of plagioclase by intergrown quartz and orthoclase, a replacement which demonstrates that K has been added to the immediate parent of the graphophyre and that Na and Ca have been expelled, probably into the rocks of Zone E, where the abundance of plagioclase indicates a culmination of Na and possibly also of Ca.

The feldspars of the graphophyre, especially the orthoclase, are markedly more kaolinized than those of any of the transitional rocks, indicating addition of water with concomitant release of K and minor amounts of Na and Ca into the migrating materials. The K was

probably fixed in the micropegmatite of the graphophyre and the Na and Ca in the oligoclase porphyroblasts of Zone E.

Short stumpy crystals of partly altered hornblende, often concentrated into small clots, occur sparingly throughout the graphophyre and are associated with magnetite. Magnetite reaches its maximum abundance in the graphophyre, suggesting that iron oxides culminate in this rock.

(*d*) *Transitional Rocks between the Graphophyre and the Microgranite.*

On approaching the microgranite the proportion of micrographic intergrowth decreases and cryptographic intergrowth appears; the corrosion effects of the plagioclase become more pronounced; the platy jointing of the graphophyre becomes less prominent and columnar jointing increases in importance. Gradually the rocks lose their graphophyric characters and approach the mineral composition and the texture of the microgranite. Since the transition takes place over a distance of several hundred yards, the boundary between the microgranite and the graphophyre is highly indefinite and the line representing it on Text-fig. 1 is consequently arbitrary. In this investigation it has been found convenient to regard rocks containing more than 50 per cent of micrographically intergrown quartz and orthoclase as graphophyres and those containing less than 50 per cent as microgranites.

(*e*) *Microgranite.*

The microgranite is similar in appearance to the graphophyre. It is composed largely of quartz and orthoclase, frequently intergrown, accompanied by smaller amounts of anorthoclase, plagioclase, hornblende, augite, and magnetite. The accessory minerals include pistacchio-green epidote, apatite, zircon, scapolite, biotite, orthite, and possibly sphene; varying proportions of secondary minerals—limonite, goethite, serpentine, chlorite, and kaolin—are also present.

The microgranite differs principally from the graphophyre in (*a*) the greater degree of corrosion of its plagioclase; (*b*) the presence of anorthoclase, and (*c*) its lesser granularity. On the other hand, there are numerous resemblances between the two rocks and these resemblances, and the gradual passage from one to the other seen on the ground, suggests that the microgranite, like the graphophyre, is a metasomatized derivative of Torridonian Sandstone. This inference is supported by the absence of any contact or marginal phase demarcating one rock from the other and by the continuation of the platy joints of the graphophyre—themselves continuations of the bedding planes of the Torridonian—into the microgranite where, although

of lesser importance than the columnar joints, they are still easily observed.

The quartz of the microgranite occurs not only as intergrowths with orthoclase, but also as discrete grains, the margins of which are occasionally coarsely intergrown with orthoclase, although their cores are free from that mineral.

Although the orthoclase of the microgranite largely occurs as micrographic and cryptographic intergrowths, large prophyroblasts, which are normally anhedral, rarely twinned, and crowded with inclusions, are of common occurrence; they appear to consist of several parts which differ slightly from each other in optical orientation. Marginally the porphyroblasts are occasionally intergrown with quartz, indicating that they have developed from quartz-orthoclase intergrowths by the increase of orthoclase and suggesting that the quartz grains which are marginally intergrown with orthoclase have developed by a similar but converse process which has resulted in the increase of the proportion of quartz in an intergrowth. The presence of porphyroblasts of orthoclase and quartz supports the metamorphic origin of the microgranite suggested by field evidence and by similarities between microgranite and graphophyre.

Large highly turbid crystals of anorthoclase occur in the microgranite. These crystals are normally anhedral and occur most frequently in parts of the rock relatively rich in green augite and plagioclase. The presence of anorthoclase in the microgranite suggests addition of soda.

Plagioclase (An_{20-25}) forms crystals of varying size throughout the microgranite. Normally the crystals are fringed directly by intergrowths but occasionally a narrow rim of orthoclase intervenes. More extensive replacement of the plagioclase by intergrown quartz and orthoclase has occurred in the microgranite than in the graphophyre and is best seen in the smaller crystals. The core of a crystal has often been removed while the peripheral portion, though locally breached, has been largely preserved. Commonly the replacement has divided the remaining plagioclase, as seen in section, into two or more fragments, each with a castellated outline and separated by intergrowth. The fragments of plagioclase would not fit together if the intergrowth were removed, and the continuity of the twin pattern, truncated by the intergrowth, shows that movement of the fragments relative to one another has not taken place. The replacement of much of the plagioclase by intergrown quartz and orthoclase indicates that K has been introduced and that Na and Ca have been expelled; the Na has probably gone to help the formation of the anorthoclase of the microgranite and the Ca has migrated outwards to Zone E or Zone C where there are culminations of this element.

In most of the specimens examined a small proportion (5 per cent or less) of hornblende is present. Normally it is a green variety but in some specimens bluish-green and brown types are also found.

In many specimens of the microgranite a green or brownish augite has been detected. It is unevenly distributed through the specimens, being most plentiful in plagioclase-rich parts of the rock. Occasionally the augite is replaced peripherally by hornblende.

Magnetite is present in small amounts throughout the microgranite, as nearly equidimensional grains and long slender rods.

4. Petrochemistry

Four analyses have been made in order to trace the chemical changes involved in the transformation of Torridonian Sandstone to microgranite (see Table).

Table

	A	I	II	III	IV
SiO_2	75·58	82·44	69·57	70·55	72·54
Al_2O_3	11·39	8·68	13·79	12·68	13·03
Fe_2O_3	0·82	0·64	1·37	2·94	1·96
FeO	1·63	1·05	3·35	2·09	1·39
MgO	0·73	0·64	1·49	0·78	0·32
CaO	1·69	0·15	1·43	1·12	0·97
Na_2O	2·46	2·28	2·66	3·92	4·04
K_2O	3·35	3·27	3·67	3·36	3·68
H_2O + 105° C.	1·07	0·56	0·88	1·28	0·90
H_2O − 105° C.	0·05	0·16	0·47	0·53	0·43
CO_2	0·51	nil	nil	nil	nil
TiO_2	0·42	0·26	0·87	0·78	0·42
P_2O_5	0·30	trace	0·12	0·13	0·03
MnO	0·05	0·04	0·09	0·07	0·06
	100·05	100·17	99·76	100·23	99·77

A. Average of Kennedy's analyses A (1), A (2), and A (3) of the Torridonian arkoses from south-eastern Skye. (Kennedy, 1951, p. 258.)

I. Composite sample of transitional rock between the Torridonian and the graphophyre, from Zone A in the outermost part of the aureole of the graphophyre in the west of Rhum. *Analyst*: W. H. Herdsman,

II. Transitional rock between the Torridonian and the graphophyre, Zone C. 2,800 yards east-north-east of the summit of Orval, Isle of Rhum. *Analyst*: W. H. Herdsman.

III. Graphophyre, 800 yards east of the summit of Orval, Isle of Rhum. *Analyst*: W. H. Herdsman.

IV. Microgranite, 2,400 yards south-west of the summit of Orval, Isle of Rhum. *Analyst*: W. H. Herdsman.

The enrichment in SiO_2 of the bleached and indurated Torridonian Sandstone of Zone A already inferred is confirmed by analysis I; comparison with an analysis of red Torridonian grit from Glenelg (Clough, 1910) and with the average (A) of three analyses of Torridonian arkoses from South-East Skye (Kennedy, 1951), shows that the bleached Torridonian of Rhum has 11 per cent more SiO_2.

Kennedy's three analysed specimens come from different horizons in the Torridonian; Clough's analysis is of a specimen collected some miles away to the east of Kennedy's. All four analyses are very closely similar and it appears that the Torridonian " arkoses " do not differ chemically to any considerable extent, either vertically or laterally.

Comparison of analyses I and II shows that Zone C has been enriched not only in K, Al, Fe, Mg, and P, but also, to a lesser extent, in Na Ca, Ti, and Mn. This considerably amplifies the inference already drawn from petrographic evidence.

The graphophyre (analysis III) belongs to the less acid group of the British Tertiary granites and granophyres. It contains less K_2O than Na_2O—a relation which is unusual in British Tertiary granites and granophyres.

From field and petrographic evidence it is known that the graphophyre has been metasomatically produced from the rocks of Zone C, three distinct stages having been recognized. The first (represented by Zone D) was characterized by addition of K_2O, CaO, and SiO_2 and subtraction of MgO; in the second (represented by Zone E) Na_2O and, to a lesser extent, CaO were added, and K_2O was subtracted; the third stage (represented by the graphophyre itself) involved slight addition of K_2O and SiO_2 and subtraction of CaO. In the case of certain constituents the successive enrichments and impoverishments more or less counteracted one another; potash, for exanple, became enriched in the first stage, impoverished in the second, and slightly enriched again in the third, the net effect being an impoverishment, as shown below.

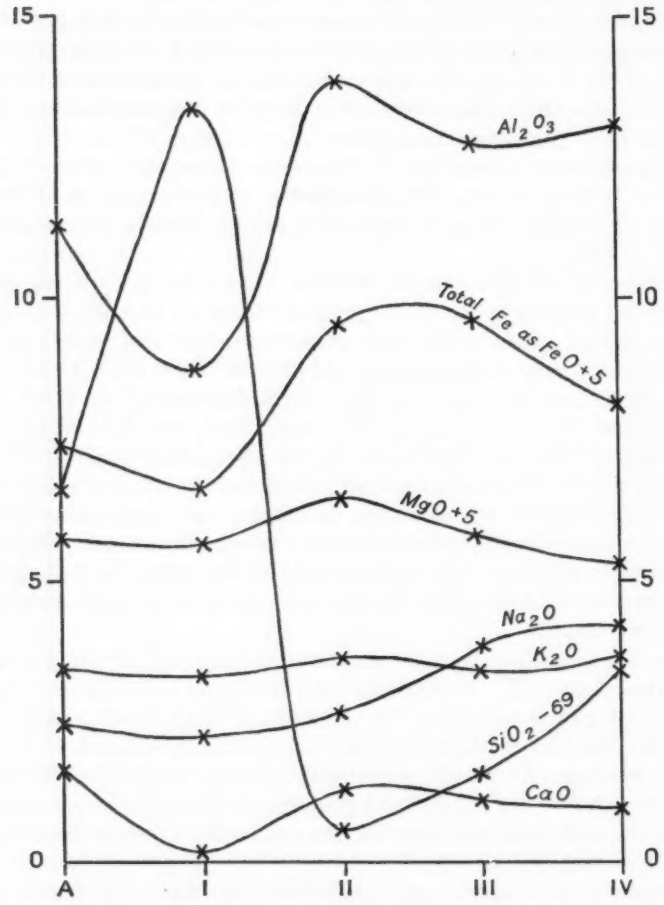
The total algebraic effect can be determined chemically by comparing analyses II and III. It is found that, compared with the rocks of Zone C, the graphophyre has been enriched in Na_2O, Fe_2O_3, and SiO_2, and has been impoverished in K_2O, CaO, MgO, Al_2O_3, and TiO_2.

The microgranite, like the graphophyre, belongs to the group of less acid British Tertiary granites and granophyres, but differs from other members of the group in that, like the graphophyre, it contains more soda than potash.

From petrographic evidence it has been inferred that the formation of the microgranite from the graphophyre involved introduction of K_2O and SiO_2, and possibly also a little Na_2O, together with some expulsion of iron oxides and, to a lesser extent, of CaO. These conclusions are borne out by a comparison of analyses III and IV. The chemical data further demonstrate that in the microgranite (IV) there has been a marked impoverishment in MgO, TiO_2, and P_2O_5, and also suggest a slight enrichment in Al_2O_3.

The total metasomatism responsible for transforming Torridonian Sandstone into microgranite has altered the chemical composition of

the former chiefly by enriching it in Al_2O_3, Na_2O, FeO, Fe_2O_3, CaO, and K_2O. Minor constituents—TiO_2, MnO, and P_2O_5—have also been added. The source of these constituents has not been traced and



TEXT-FIG 2.—Variation diagram illustrating the chemical changes which occurred in the transformation of Torridonian Sandstone into microgranite. For A, I, II, III, and IV, see Table.

it can only be postulated that they have been introduced into the Torridonian from depth. The bulk of the material expelled from the now transformed Torridonian was SiO_2.

The source of the SiO_2 which has been introduced into Zone A (p. 261 and analyses A and I) presumably lay to the south; the silica

expelled from the acid and transitional rocks to the south has been driven outwards and is now lodged in Zone A, where it culminates and forms an " acid front ".

A comparison of analyses A and I also shows that Zone A is poorer in Al_2O_3, FeO, and Fe_2O_3 than the Torridonian. The differences can be explained by slight differences in their contents of argillaceous material and sericite, and of magnetite and chlorite. There is no evidence suggesting that excess Al_2O_3 has been driven outwards from Zone A to form a separate " front " further to the north.

Culminations and depressions of various constituents in the acid and the transitional rocks are graphically represented in Text-fig. 2, viz. culminations of Al_2O_3, FeO, TiO_2, CaO, MgO, and MnO in Zone C; a slight depression of SiO_2 and a secondary culmination of K_2O in Zone C; and culminations of Fe_2O_3 and P_2O_5 in the graphophyre.

The geochemical changes which have affected the Torridonian rocks of the west of Rhum are of the same kind as those inferred by Dr. D. L. Reynolds (1946) from a study of geochemical data from some thirty areas where metasomatism has taken place. She writes of the emplacement of granite (p. 434) that it " involves an . . . enrichment of an adjoining zone of the neighbouring rock in alkalis, one or more of the cafemic constituents, and one or more of the minor constituents TiO_2, P_2O_5, and MnO, some or all of which show geochemical culmination ". In the west of Rhum the rocks adjoining the acid rocks have been enriched in alkalis, in all three cafemic constituents, and in all three minor constituents.

5. Conclusions

Structural, petrological, and chemical evidence converge in showing that the microgranite, graphophyre, and transitional rocks between the latter and the Torridonian Sandstone have been produced by metasomatic and metamorphic transformation of the Torridonian Sandstone while the rocks remained essentially in a solid state. It has been found practicable to recognize six characteristic stages of what was doubtless a continuous process of transformation. The original Torridonian rocks have been enriched in Al_2O_3, Na_2O, FeO, and Fe_2O_3. SiO_2 was the main constituent expelled from the Torridonian; evidence is provided that the expelled SiO_2 is fixed in the acid front represented by the bleached and indurated rocks of Zone A.

The main conclusion of the present paper, namely that the acid rocks of the west of Rhum are the metamorphosed representatives of the Torridonian Sandstone, is the same as that reached by King (1953) as to the origin of the granophyres of the Creag Strollamus area in Skye. The contact phenomena between the granophyre and Torri-

donian in Skye, as described by King, seem to be similar to those found between the graphophyre and Torridonian in the west of Rhum.

ACKNOWLEDGMENTS

The author is greatly indebted to Professor Arthur Holmes and to Dr. D. B. McIntyre for their constructive criticism of this paper. He would also like to thank Lady Bullough for the many facilities afforded the author during the numerous periods of his field work on Rhum.

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GRANT INSTITUTE OF GEOLOGY,
THE UNIVERSITY OF EDINBURGH.

The Pegmatites of Trolvis Quarry, Carnmenellis, Cornwall.

By K. F. G. Hosking

(PLATE VI)

Abstract

The pegmatites of Trolvis Quarry, Carnmenellis, are small lenticular masses which were developed before the joints of the associated granite. Both mineralogically simple and complex types occur : the latter are drusy. Whilst the earlier minerals lining the druses may have crystallized in a closed system, the later minerals were clearly deposited from a moving phase. The disposition of the later minerals was largely determined by earlier crystals acting as baffles to the mineral-depositing agents. The pegmatites appear to occupy spaces formed by the solution of the granite by a pegmatitic fraction of the magma.

THE pegmatites discussed in this paper occur in Trolvis Quarry, situated in the east central portion of the Carnmenellis mass, which is one of the exposed portions of the Permo-Carboniferous granite batholith underlying Cornwall and West Devon (Text-fig. 1).

These pegmatites, although not large, are of interest, not only because of the considerable variety of minerals found in some of them, but also because they provide valuable information concerning some of the processes of pegmatite development.

The Carnmenellis Granite

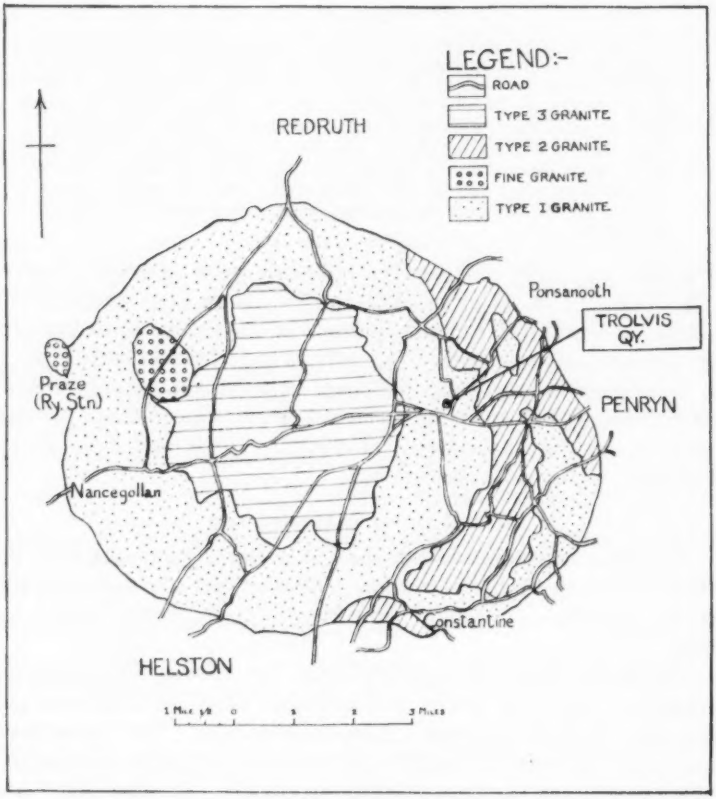
According to Ghosh (1934), the Carnmenellis mass was built up by successive emplacement of three dominant types of granite, and the quarry in question occurs in the earliest granite, termed Type 1 by him.

The granite within the quarry displays well-developed cleavingway, toughway, and floor joints and although other joint systems are apparent, their development is comparatively poor. The cleavingway and toughway joints are approximately vertical and strike at about 25° west of north and 65° east of north respectively. The floor joints are approximately horizontal and the distance between them tends to increase with depth below the surface.

The quarry in question is not a large one and is concerned primarily with the production of rock for kerbstones and the like, the amount removed annually being comparatively small. Thus, at any particular time, only a small volume of fresh rock is available for examination and as the granite is removed mostly in the form of rectangular prisms, much of the quarry exhibits a step-like profile. Consequently any individual pegmatite can usually only be examined for a few yards along its dip or strike at any given time. However, for reasons apparent later, this does not constitute a serious drawback.

General Characteristics of the Pegmatites

During the working of the quarry pegmatites have been encountered in many portions of it, but at present they are mostly exposed in the north-west part.



Text-fig. 1.—Sketch map of the Carnmenellis granite. Modified after P. K. Ghosh (1934, p. 241).

These pegmatites are essentially steeply dipping, vein-like bodies, which rapidly alter in width along the dip and tend to develop at varying horizons into comparatively small lenticular masses. The dip varies from one pegmatite to another and not infrequently the slope of an individual pegmatite changes rapidly from one level to another, so that in a vertical distance of 4 to 5 feet the body is sometimes markedly curved.

Whilst the quarrymen are of the opinion that the pegmatites vary in

strike direction, those which the author has examined all strike at about 10° east of north.

Although the dimensions of the pegmatite lenses are subject to considerable variation, any given one seldom extends for more than 2 feet along the strike and dip, and rarely has a maximum width in dip section greater than 6 inches. Occasionally, however, a lens may be about a foot longer than this along the dip and strike, and attain a maximum width of 18 inches. These wider lenses always contain central cavities, lined frequently with an interesting mineral assemblage.

Usually it is difficult to trace the pegmatite beyond the lens. Indeed, its extensions may be indicated by nothing more than an occasional large feldspar crystal, a book of pegmatite mica, or a large tourmaline crystal developed along the prolongation of the lens axis.

The junction between the granite and the pegmatite lenses is always undulatory, but is reasonably well-defined because of the sudden diminution in dark-brown biotite when passing from granite to the feldspar-quartz marginal zone of the pegmatite.

It is clear that the pegmatites were formed before the granite joints, since they are intersected by the latter and differ from them in dip and strike. No obvious movement has taken place along these joints, as the pegmatites transversed by them show no signs of displacement.

Mineralogical Characteristics of the Pegmatite Lenses

The pegmatite lenses within the quarry show considerable variation, both in the relative proportions of minerals and the number of species present.

(*a*) *Simple Pegmatites.*

From a mineralogical point of view, the *simplest lenses* consist of perthitic feldspar, quartz, deep-brown tourmaline, and pale brown to white muscovite mica. In the smaller lenses the feldspars, which invariably show Carlsbad twinning, are white, and the largest (about 3 inches in length) differ only from the feldspar phenocrysts of the granite in being from two to three times as long. In several of the lenses many of the larger, earlier formed feldspar crystals are orientated in the same manner as the feldspars of the surrounding granite. This is due to the continued growth of some of the marginal granite feldspars into the pegmatite zone, a development which also determined, to some extent, the orientation of the later true pegmatite feldspars.

Feldspar development is densest around the periphery of the lenses, where there is also a considerable amount of contemporaneous quartz. The cores of the lenses are also composed largely of quartz and feldspar crystals, but these, unlike their peripheral counterparts, show a more random orientation.

In the simplest lenses, tourmaline is never abundant but is invariably present as deep brown crystals, often about a quarter of an inch wide and an inch long. These crystals may occur in any part of the lens except the marginal portions, and they show random orientation. In the larger lenses there is a tendency for maximum tourmaline development to occur in the uppermost portions of the core. Books of pale brown muscovite mica, often about a quarter of an inch in width, are randomly distributed within the heart of the pegmatites.

Lenses of this type were developed in the following manner. A quartz-feldspar border zone was initiated, some of the components being simply pegmatite-phase extensions of the feldspar and quartz crystals of the granite. After the marginal portions of the border zone were formed, tourmaline crystals developed and these, in some cases, grew most profusely in the upper part of the lens. At the same time the earlier-initiated feldspar and quartz crystals continued to grow and new quartz and feldspar crystals formed: both these minerals partially, or entirely, invested the tourmaline crystals. During the final stage of quartz-feldspar development, and sometimes shortly afterwards, pale brown mica was deposited.

(*b*) *Complex Pegmatites.*

The characteristics of the complex pegmatites may best be indicated by describing the most spectacular example and noting any important variations between it and others in the quarry.

The undulatory margin of this comparatively large lens is emphasized by the abrupt change from dark biotite-rich granite to a quartz-feldspar border zone about half an inch thick. Inside this zone is a band composed of much larger crystals of feldspar and quartz, together with numerous scattered groups of randomly-orientated brown tourmaline crystals, which reach a maximum length of three-quarters of an inch and a width of about one-tenth of an inch.

Continued deposition of quartz and feldspar resulted in the development of large Carlsbad-twinned creamy-white perthitic-feldspar crystals and equally large crystals of transparent alpha-quartz. In some instances these crystals project for 1½ to 2 inches beyond the border zone, into the central cavity. The largest and best developed feldspar crystals display a basal pinacoid, two sets of hemi-orthodomes, clinopinacoids, prisms, and a hemi-bipyramidal face. The quartz crystals projecting into the open cavity, approximately at right angles to the medial plane of the lens, display an unequal development of rhombohedral faces in such a manner as to suggest crystallization from agencies moving in one constant direction (see Newhouse, 1941). It is an interesting fact that the hemi-bipyramidal faces of the projecting feldspar crystals always face the upper part of the lens. This

may be due to the building up of the crystals from material carried by ascending " solutions ", as there is a tendency for terminal faces to be smaller on the side exposed to the oncoming solutions; in the extreme case, a given crystal face may fail to be developed at all.

The following points concerning the feldspar-quartz development are also of considerable interest: (1) The upper portions of the druse are lined essentially with projecting feldspar crystals, whilst the intermediate parts are lined with approximately equal amounts of projecting feldspar and quartz crystals, and in the lower sections large quartz crystals predominate over feldspar crystals.

(2) Those feldspar and quartz crystals which are situated in the lower parts of the druse are much more richly encrusted with later minerals than those in the upper horizons. Furthermore there is a general decrease in the size of the encrusting crystals of any given mineral species towards the apex of the lens.

(3) A few of the feldspar crystals projecting into the central cavity are terminated by fractured surfaces encrusted with later minerals, which suggests they were broken during the developmental stages of the pegmatite.

During the earlier growth stages of the large quartz and feldspar crystals, scattered books of pale brown muscovite mica, sometimes three-quarters of an inch across, were deposited. Long after the phase of mica development ceased, however, the earlier-initiated feldspar and quartz crystals continued to grow and other new feldspar and quartz crystals were developed.

Other lenses are much richer in tourmaline and in several of these there were distinct periods during which the mineral was deposited. The earlier tourmaline crystals are deep brown, often an inch long and a third of an inch wide and are sometimes partially or entirely enveloped by large quartz or white feldspar crystals. Their development commenced soon after the earliest quartz and feldspar and they grew contemporaneously with the large feldspar and quartz crystals. These latter crystals continued to grow after the large tourmaline crystals had ceased to do so.

The later tourmaline consists of myriads of brown, needle-like crystals, often an inch long but seldom more than a millimetre wide. They are most profuse in the upper parts of druses and some of them were partially entrapped by large feldspar and quartz crystals during the final phases of development of the latter. Some of these tourmaline crystals fringe bodies which were once feldspar crystals but are now composed of a quartz-tourmaline border zone surrounding a pink feldspar core. In the vicinity of later tourmalines the feldspars are pink and the faces upon which the mineralizing agencies impinged are markedly corroded.

The early tourmaline crystals were deposited directly from a magmatic fraction carrying the complete components for their development. On the other hand, the later tourmalines were developed from agents which obtained some of their ingredients from feldspars. The feldspars were either replaced by tourmaline and quartz or, as was more frequently the case, some of the feldspar was dissolved and the material transported and utilized elsewhere for the formation of tourmaline.

Topaz crystals, occurring in aggregates never more than 6 mm. wide, are seen in some lenses. These crystals are colourless and are characterized by a marked development of the basal pinacoid. They often invest tourmaline of the second generation and were probably deposited immediately after it.

The main feldspar-quartz stage was followed by the development of numerous books of white mica, rarely more than a quarter of an inch across, superimposed largely upon feldspar crystals, but also to some extent on quartz crystals. These books show their maximum development on crystal faces pointing in the direction from which the ascending depositing agencies were coming, and the paths followed by these " solutions " are thus clearly indicated (Plate VI, figs. 1 and 2).

Whilst there is a slight development of white mica on the leeward side of many of the feldspar crystals, there is none on the leeward side of the quartz crystals. This is an interesting example of preferential crystal deposition on one mineral rather than on another, for there is no evidence that the mica on the feldspar has been developed by replacement.

The stage of white mica development was followed by the growth of yellow gilbertite mica. This mica occurs as very small yellow flakes, sometimes covering all the faces of projecting feldspar crystals and books of white mica, but only covering those faces of quartz crystals which face the bottom of the cavity. Whilst there is evidence of a slight development of gilbertite by replacement of feldspar along cleavage planes, the gilbertite occurring on feldspar faces appears to be the product of direct deposition rather than of replacement. That this is probably correct is borne out by the occurrence of gilbertite, as stated above, on quartz crystals. The much more widespread development of gilbertite on feldspar than on quartz appears to be yet another example of preferential deposition on one mineral rather than on another. Both white mica and gilbertite become progressively smaller towards the top of the lens.

The gilbertite stage was followed by the development of tabular, blue-grey fluor-apatite crystals which display on their basal face a series of narrow colour zones parallel to the prism walls. These zones are various shades of grey-green and blue-green, separated by colourless

bands. In other lenses crystals with similar characteristics are seen enveloping needle-like tourmaline crystals. Minute quartz crystals partially invest some apatites and the adjacent large feldspar and quartz crystals. Apatite crystals are only found on surfaces facing the direction of flow of mineralizing agents, which followed the same paths as the fluids responsible for growth of white and gilbertite mica. During the apatite phase the largest crystals were deposited in the lowest parts of the lenses and there was a progressive decrease in size at higher levels.

The apatite stage was succeeded by one in which fluorite was developed from fluids which continued to follow the previously established paths. In one instance, however, one of the paths was blocked by an earlier deposition of white mica books so that neither apatite nor fluorite could develop within it. During this fluorite stage also, the largest crystals were deposited in the lowest sections of the lenses.

The habits of the fluorite crystals are very variable and the largest crystals are composed of green to colourless cores surrounded by deep-purple peripheral zones. Of these the largest exhibit cubic and almost equally well-developed octahedral faces. On the octahedral faces numerous small octahedra show parallel development, whilst small crystals along the junction of parent octahedral faces consist of octahedra modified by rhombic dodecahedral faces. The longer diagonals of the dodecahedral faces are orientated parallel to the intersection of the octahedral faces of the parent crystal.

Several slightly smaller crystals, with green centres and purple peripheries, are octahedral in habit and their faces are covered with small octahedra showing parallel development. At the intersection of the parent octahedral faces, small octahedra, modified by rhombic dodecahedral faces, occur under exactly the same conditions as those described above.

A still smaller group of fluorite crystals with green cores and purple peripheries display well-developed cubic faces together with slight octahedral and rhombic dodecahedral faces. In one instance a small purple octahedron developed on an octahedral face of the parent crystal. Another group consists of small crystals with very pale green cores surrounded by thin purple peripheral zones, the individual crystals being octahedra, slightly modified by rhombic dodecahedral faces. The smallest crystals are either purple dodecahedra modified by a slight development of octahedral faces, or simply purple rhombic dodecahedra.

As there is a general decrease in crystal size towards the top of the lenses, it cannot be said with certainty that the largest fluorite crystals were the first to commence growth, although this was very probably the case. The small, entirely purple crystals, were undoubtedly the last to be formed. It seems reasonably certain, however, that with the

passage of time the cubic habit tended to give way to the octahedral and it in turn was generally succeeded by the rhombic dodecahedral habit.

Whether this variation in crystal habit is due partially or entirely to differences in the temperature at which deposition took place, or whether it is due partly or wholly to changes in the character of the mineralizing agents from which the crystals were developing, is unknown. The change in colour from green to purple indicates that the character of the fluid from which deposition was taking place was certainly altering. The order of change of habit described above is at variance with that suggested by Drugman (1932) as taking place under conditions of declining temperature. He is of the opinion that the octahedral habit is the high temperature type, the cubic habit the low temperature, and that somewhere between the temperatures of development of these two types lies the stability range of the rhombic dodecahedron.[1]

Following the period of fluorite development, there was a stage when clusters of small, colourless untwinned-crystals of bertrandite were deposited from mineralizing agencies which followed the same paths as those taken by the earlier solutions. These bertrandite crystals are found clustering on feldspars, quartz, white mica and apatite, and are banked up against fluorite crystals, though they are not actually seen " seated " upon the latter. They are prismatic in habit and are composed of ortho- and clino-pinacoids, orthodomes and slight basal pinacoids. Dana (1934, p. 632) suggests that bertrandite is probably an alteration product of beryl, but there is no evidence at Trolvis Quarry that this is so. Furthermore, Russell's description of other occurrences of bertrandite in Cornwall offers no suggestion that any bertrandite examined by him is of secondary origin.

The bertrandite stage was followed by a slight development of chlorite, which is most marked towards the bottom of the druse where it occurs in the form of small scales investing faces of feldspar, quartz, and mica crystals. In those areas where the chlorite development is most conspicuous some chlorite-free feldspars are slightly pink and some of their faces are distinctly corroded. It would appear, therefore, that ascending solutions removed some of the constituents of the feldspar and utilized them for chlorite development elsewhere. Nevertheless, a slight amount of chlorite was developed by replacement along the cleavage planes of some feldspars.

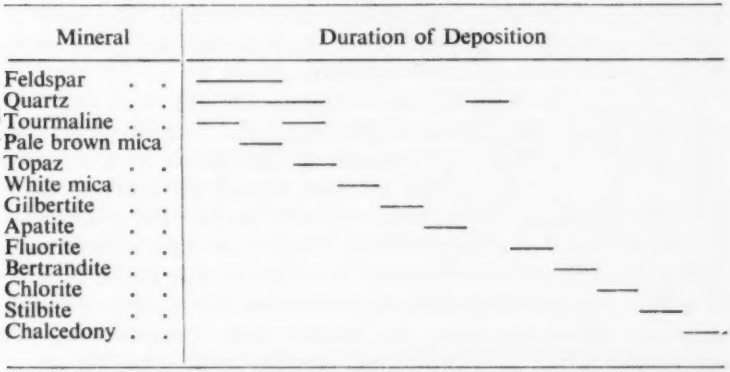
The chlorite stage was succeeded by one in which a few radiating

[1] Any relationship which exists between fluorite habit and temperature of formation, could best be investigated by the decrepitometric method, developed by F. Gordon Smith (1952), provided, of course, that the mineral was deposited from solution.

clusters of white stilbite crystals about three millimetres long were deposited. These crystals are found investing both feldspar and quartz faces and chlorite-covered mica books. Their occurrence is such as to indicate that they were deposited from agencies which moved along the same paths as those used by earlier mineral-depositing agencies. They are found only at, or near, the base of the cavity.

Finally, a certain amount of ochre-coloured chalcedony was deposited between some of the projecting crystals at the bottom of the cavity.

The mineral paragenesis of the complex pegmatites appears to be as follows:—



Observations on the Mode of Development of the Pegmatites

In the opinion of Ghosh (1934), the Carnmenellis mass is composed of three dominant types of granite, of which Type 1, in which the pegmatites under discussion occur, is the oldest. Trolvis Quarry is situated on a comparatively narrow exposure of Type 1 granite which is bordered on the east by Type 2 granite and on the west by Type 3. As there is a general tendency for pegmatites to develop near the junction of the parent intrusive with the overlying rock, and as it is likely that the upper portions of Type 1 granite have been eroded, it is probable that the pegmatites at Trolvis Quarry are genetically related to Type 2 and/or Type 3 granite. As the underground extensions of these later granites are not known with certainty either could have supplied the pegmatite material.

As a result of magmatic pressure, the light pegmatite fraction invaded the granite roof along the planes of maximum weakness, by a process of wedging.[1] The extension of any given fissure by this process could only continue as long as the magmatic pressure was greater than that

[1] This mechanism is similar to that advocated by Anderson (1942, pp. 21–6) for the development of porphyry dykes.

exerted by the overlying rock. It is to be expected that fluctuations in magmatic pressure should be such that during comparatively short periods of geological time it might be greater than, equal to, or less than the pressure of the overlying rock. Whenever the magmatic pressure equalled or was only slightly in excess of the rock pressure, the fissure ceased to be extended or was lengthened only very slowly. The magmatic wedge then exerted a solvent action upon its confining walls, especially at the apical region where the lightest fractions tended to accumulate.

The field evidence suggests that these solvents preferred to attack the smaller crystal components of the walls, thereby producing irregular walls which, in the apical regions, are markedly curved. As a result of the further changes mentioned below, these curved portions became, in due course, the walls of the pegmatite lenses.

At Trolvis, the stage of chemical attack on the wall rock was followed by a period when the magmatic pressure once again considerably exceeded the wall rock pressure, so that fissures were extended rapidly. How far the fissures extended beyond the quarry horizon can only be guessed at, but they probably reached the granite-slate contact at least, because the evidence is clear that mineralizing agents moved along them in one direction for a considerable period of time. It is likely that those parts of the mineralizing fluids which were not deposited within the lenses and fissures under discussion induced pneumatolytic and/or hydrothermal changes in the overlying cooler granite and in the near-contact slate.

The marked change in dip encountered in some of the pegmatitic bodies may well have been due to large feldspar crystals within the granite acting as deflecting wedges during the stages of fissure development.

Following the final phase of fissure formation and whilst the temperature was too high to permit mineral deposition within the fissures, it is suggested that the magmatic pressure decreased to such an extent that it was exceeded by the wall rock pressure. This caused the walls of the fissures to approach each other, so that the only spaces available for appreciable deposition were within the areas, now lenticular in dip section, where wall-rock solution had been most effective. Complete closure of the fissures, both above and below the lenses, was not caused by the above mechanism, because the walls were, as a result of differential solution, uneven.

The field evidence suggests that the fissures connecting the lenses to the source of the material being precipitated within them were extremely narrow. The fact that different lenses show varying mineral assemblages and that the relative proportions of minerals present in the lenses vary, suggests that the fissures were only open

intermittently during the period of pegmatite development. Periodic fissure closure was probably due to crystal deposition, whilst intermittent re-opening was occasioned by the fracturing of crystals and by vibrational movements such as one would expect to occur in a comparatively thin granite crust above consolidating magma. That such movement did take place is indicated by the fact that within the lenses some of the tourmalines have clearly been fractured and recemented, and in one particular lens several fluorspar crystals have been cracked and recemented by later mica. Furthermore, there are fractured feldspar crystals in the largest lens examined, the broken surfaces of which are partially covered by small fluorite crystals.

As a result of declining temperature, pegmatite development eventually took place within the available spaces and was naturally most marked in the lenses. Here it started with the renewed growth of some of the feldspar (and probably quartz) crystals of the walls, and the establishment of new feldspar and quartz centres of crystallization. Shortly after the initial feldspar-quartz stage, tourmaline and pale brown muscovite mica were deposited.

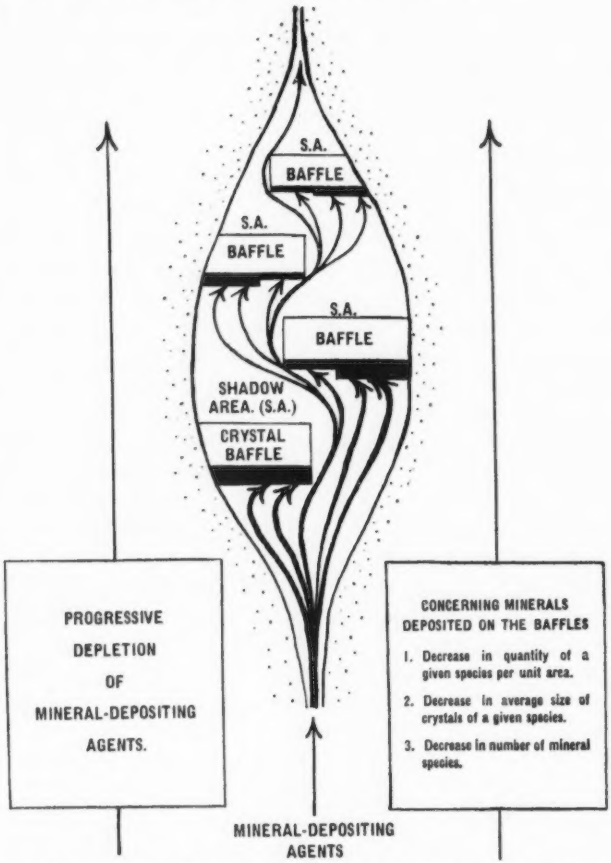
Whether these early pegmatite minerals were deposited from more or less static material trapped within the lens during the stage of "wall closure" or whether they were deposited from pegmatitic magma which was slowly moving along the fissures, cannot be ascertained.

It is suggested that the last of the large feldspar and quartz crystals to be formed were developed from a moving magmatic fraction and it is certain that the still later minerals were so developed.

Replacement during the growth of the pegmatites was of a very subsidiary nature and only contributed towards the development of some of the late tourmaline, gilbertite-mica and chlorite. The corroded nature and reddening of the feldspars in areas where there is conspicuous development of second generation tourmaline or of chlorite suggests that the ascending solutions derived some of the ingredients necessary for the development of these later minerals by partial solution of the feldspar crystals.

Decrease in both the size and number of later crystals per unit volume in passing from the lowest to the highest horizons of the druses, is clearly due to the earlier large feldspar and quartz crystals acting as baffles, upon which the later minerals were deposited mainly on those portions which faced the ascending current of mineral-depositing agents (Text-fig. 2). These agents, after impinging upon any given baffle would, if crystallization took place there, ascend to higher levels in a depleted state. This inducement of deposition by crystal baffles must be one of the major factors controlling the late mineralogical variations so often encountered in pegmatites as they are traced away

from their source. Furthermore, it is probably a factor of much more importance than has yet been generally realized in the localization of all but the earliest minerals found in fissure lodes.[1]



TEXT-FIG. 2.—Diagram illustrating the method of later-mineral deposition within a pegmatite cavity.

That the development of the late minerals is most marked in the large druses is doubtless due to some extent to a decrease in the velocity of the fluids as they entered the wider channel.

Finally, variation in the mode of development of the earlier and later tourmalines indicates that with passing time there was at least one major change in the nature of the agent from which the minerals were

[1] This aspect of crystal deposition has been discussed by Newhouse (1941).

FIG. 1.

FIG. 2.

TYPICAL FELDSPAR BAFFLE IN CARNMENELLIS PEGMATITE.

deposited. It is probable that whilst the earlier feldspar and quartz, together with the pale brown mica and large tourmalines were deposited from a flux-rich magma, the later minerals crystallized either from a vapour phase followed by a liquid phase or entirely from a liquid phase.

In conclusion the author wishes to express his appreciation and thanks to Messrs. Spargo, the quarry owners, for allowing him frequent access to the quarry, and for preserving many interesting specimens for him. Thanks are also due to Mr. Nicholas of the Camborne School of Mines for preparing the photographs. Mr. Jobbins of the Geological Survey Museum, kindly confirmed the identity of bertrandite, and Dr. Webb, of the Imperial College, generously allowed the author access to his observations on certain Cornish pegmatites which are contained in his unpublished doctorate thesis. To Professor David Williams the author owes his gratitude for valuable criticisms and suggestions.

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CAMBORNE SCHOOL OF METALLIFEROUS MINING,
CORNWALL.

EXPLANATION OF PLATE VI

FIG. 1.—A large feldspar crystal from Trolvis, showing deposits of mica, apatite, fluorite, and bertrandite on the faces upon which mineralizing agencies impinged.

FIG. 2.—The " leeward side " of the feldspar crystal shown in Fig. 1. Here, there is only a slight encrustation of white and gilbertite mica. × 2.

The Granite–Diorite Complex of the Insch Igneous Mass, Aberdeenshire

By M. S. Sadashivaiah

Abstract

A complex of granitic, syenitic, and dioritic rocks forms the western part of the Insch mass. All these rocks appear to be related, but they are later than, and have no direct connection with, the basic rocks forming the bulk of the Insch mass. The granitic and syenitic varieties are fairly uniform, but the dioritic types are variable rocks rich in xenoliths which are apparently derived from basic rocks. It is suggested that the diorites were formed by contamination of the magma producing the granitic and syenitic rocks.

Introduction

THE Insch igneous mass, which is the largest of the intrusions forming the " Newer Basic " province of igneous activity in North-East Scotland, consists predominantly of gabbroic rocks. A group of more acid rocks appears, however, in the Kennethmont and Clatt districts, in the western part of the mass. These rocks include granitic and syenitic types which have been contaminated by basic material, with the production of xenolithic diorites.

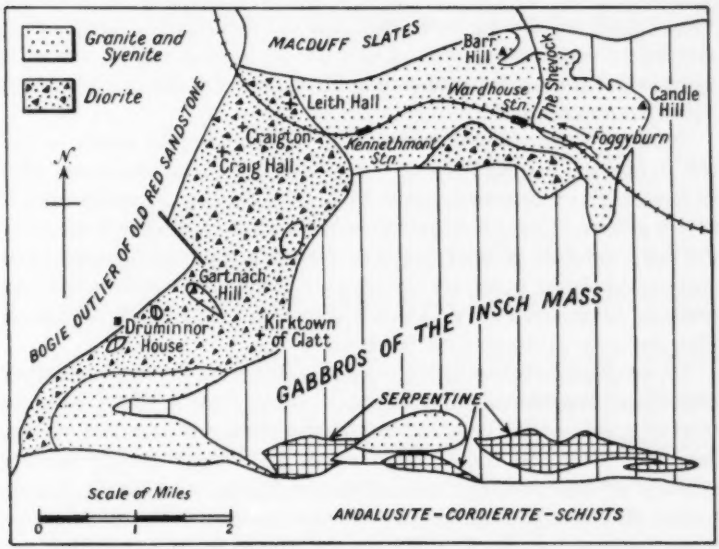
The writer has recently undertaken, in conjunction with Professor H. H. Read, a study of the whole Insch mass, the results of which will be discussed in another publication. The granite-diorite association which is the subject of this note forms a unit which has little to do with the problems presented by the much more important gabbros and may therefore conveniently be described separately. The rocks of the group are not directly derived from the gabbros and in this respect may be contrasted with certain other syenitic rocks in the Insch mass, which will be described elsewhere.

Little has been written of the granite-diorite complex of the Insch mass. The rocks lie partly within Sheet 76 and partly within Sheet 86 of the 1-inch Geological Survey Map of Scotland, and are described in the respective Memoirs by L. Hinxman and J. S. G. Wilson (1890), and by H. H. Read (1923). In the earlier publication the diorites were considered to be related to the gabbros, and the granites and syenites to belong to a later intrusion. Read described the rocks under the headings of " Quartz-diorite " and " Syenite and granite ". He showed the last two types to be linked by transition-forms but expressed no views on their relation to the quartz-diorite.

Distribution

The distribution within the Insch mass of granitic, syenitic, and dioritic rocks of the types to be described is shown in Text-fig. 1. The granitic and syenitic rocks are best developed in the area around

Wardhouse, and along the southern border of the mass, to the south-west of Clatt, where they are in a mylonitized or brecciated condition. Closely associated with these rocks are xenolithic quartz-diorites, which occur at the west end of the Insch mass where they are covered by Old Red Sandstone. Similar dioritic rocks are seen on the rising ground south of Wardhouse Station and also in small amounts at many localities in the main granite areas. Around Jackston at the northern contact of the Insch gabbros 12 miles to the east of Kennethmont Station there is a complex of granitic and dioritic rocks similar to



TEXT-FIG. 1.—The western end of the Insch Igneous Mass, Aberdeenshire.

those of the areas further west; the complex includes granite, diorite, various hornfelses, and tourmaline pegmatites, but the exposures are too poor for profitable investigation.

The main body of the complex at the west end of the mass is also rather poorly exposed and little can be learned of its relation to the surrounding rocks. The granitic and dioritic rocks are bounded on the west by unconformable Old Red Sandstone, and on the east by hypersthene- and olivine-gabbros of the main igneous mass; to the north and south, respectively, they are succeeded by hornfelsed Macduff Slates and andalusite-cordierite-schists of the Fyvie Group, which make the country rocks of the Insch intrusions. The granites and diorites most likely form a thin sheet separating the basic rocks from the metamorphosed sediments of their roof.

Granitic and Syenitic Rocks

The granitic type is a fine-grained pink rock and the "quartz-syenite" is a coarser rock with large feldspar crystals and patches of biotite; the two extremes are linked by transitional varieties. All the rocks are usually deeply weathered.

At the eastern end of the Wardhouse body, coarse granitic rock is seen in contact with overlying gabbro on the top of Candle Hill. A sinuous contact can be mapped north-westwards from the base of this hill across the Foggyburn into the Shevock. West of the Shevock, a quarry south of Barr Hill shows a pink granite in contact with spheroidally-weathering basic rock, the contact dipping fairly steeply northward under the gabbro. From the evidence available, it may be suggested that the granite sheet thins out eastward and is locally covered by a thin gabbro roof.

South of Kennethmont, small areas of granitic rocks appear within the diorite as, for example, at Kings Hillock and at Gartnach Hill; in a quarry at the latter locality the granite encloses rounded balls of rotten gabbro. Granitic dykes, presumably derived from this intrusion, cut the hornfelsed Macduff Slates in the Leith Hall and Shevock areas and similar dykes penetrate the gabbros at various localities near the contact. All the evidence thus indicates that the granitic body is younger than the main gabbros of the Insch mass.

The main constituents of the *granitic varieties* are quartz, microcline, oligoclase, hornblende, and biotite. Quartz forms large patches, smaller grains at the edges of microcline plates, or scattered pellets. Perthitic microcline builds large plates into which project smaller euhedra of scarcer oligoclase. Greenish-brown hornblende, brown biotite, and iron oxide are present in scanty amounts. The analysis of a typical granite from the Barr Hill quarry is given in Table I.

The *syenitic varieties* are coarser in grain, richer in ferromagnesian components, and contain only small amounts of quartz. The latter mineral occurs in the interstices between the feldspars or forms narrow edgings to them. The hornblende is a deeply-coloured brown to greenish-black type and is associated with large ragged flakes of yellow to deep brownish-black biotite.

The Dioritic Rocks

Rocks of dioritic composition crop out in the series of wooded hills that form the extreme western part of the Insch mass. They are fairly well seen in the woods north and west of Leith Hall, where they are rather variable greyish rocks containing small enclaves of darker and finer-grained material; they appear to pass eastward into the syenite north of Leith Hall. In the deep railway cutting beside the Kennethmont graveyard the quartz-diorite is a more uniform type

TABLE I.—GRANITIC AND DIORITIC ROCKS

	1.	2.	3.	4.	A.	B.	C.	D.
SiO_2	77·36	56·07	55·14	51·88	50·70	57·13	56·68	49·30
Al_2O_3	10·01	13·18	18·33	16·24	23·40	15·40	16·54	14·03
Fe_2O_3	0·84	1·22	2·21	0·95	1·77	1·13	1·59	0·09
FeO	0·56	7·47	7·24	8·39	5·02	5·52	6·21	9·61
MgO	0·09	4·87	2·83	6·84	2·35	4·36	4·45	6·82
CaO	0·72	7·01	6·06	7·96	3·80	5·19	6·70	12·31
Na_2O	3·28	2·79	3·34	2·76	4·45	3·03	3·72	2·66
K_2O	5·10	2·44	2·25	2·64	4·38	4·44	1·57	0·30
H_2O+ } H_2O- }	0·34	1·02	1·02	0·78	2·50	0·72	0·60	0·87
CO_2	0·44	0·63	—	—	—	—	—	0·42
TiO_2	0·18	2·38	1·48	1·14	1·14	3·00	1·56	3·19
P_2O_5	0·98	0·23	0·08	0·07	0·08	0·31	0·27	0·05
S	—	—	—	—	0·29	—	—	—
FeS_2 } Fe_7S_8 }	—	0·36	—	—	—	—	—	0·08
MnO	0·12	0·26	0·17	0·19	0·18	0·02	—	0·31
BaO	0·04	0·14	—	—	—	—	—	—
F	—	—	—	—	—	—	0·02	—
	100·06	100·07	100·15	99·84	100·06	100·25	99·91	100·04

1. Granite, quarry ¼ mile S.E. of Weets, Insch. *Anal.*; E. G. Radley (Read, 1923, p. 124).
2. Quartz-diorite, Graveyard Railway Cutting, 430 yards S.S.E. of Leith Hall, Kennethmont, Insch. *Anal.*; E. G. Radley (Read, 1923, p. 124).
3. Quartz-diorite, Railway Cutting, 150 yards E. of Graveyard, Kennethmont, Insch. *Anal.*; Herdsman.
4. Enclave in quartz-diorite, 210 yards W. of N. of Craig Hall, Kennethmont, Insch. *Anal.*; Herdsman.

A. Igneous basic inclusion in Dhoon granite. *Anal.*; Herdsman (Nockolds, 1931, p. 504).

B. Igneous xenolith in tonalite. Cairnsmore of Carsphairn complex. (Deer, 1935, Table, Analysis 6.)

C. Hornblende hybrid, large xenolith in tonalite, Cairnsmore of Carsphairn complex. (Deer, 1935, Table, Analysis 10.)

D. Hypersthene-gabbro of the Insch Mass, ½ mile W. of Bridgend of Shevock, Insch. *Anal.*; E. G. Radley (Read, 1923, p. 124).

without conspicuous enclaves. South of the railway, around Craigton, Craig Hall, and southward to Gartnach Hill, the dioritic rocks are patchy, with fine-grained dark grey patches set in coarser more acid material with acid, almost granitic, veins and stringers. Enclave-bearing quartz-diorites, more granitic types, also with enclaves, and normal granites can be seen in poor exposures east of Druminnor House and at various localities further south.

It will be seen from the description given above that the dioritic rocks pass into enclave-bearing granitic types and into the more normal granite and quartz-syenite which have already been described.

The *xenolithic rocks with granitic matrices* are pink in colour and are speckled with dark or fine-grained patches; they are richer in

biotite and generally poorer in potash feldspar than the normal granite of Kennethmont. Oligoclase, quartz, orthoclase or microcline, biotite, and occasional hornblende, with accessory iron oxide, apatite, orthite and sphene are present. Squarish or lath-like oligoclase crystals lie with a random orientation in a granular matrix of potash feldspar and quartz. Sieved plates of biotite are scattered through the rock or aggregated in clots that often contain also sieved prisms of hornblende.

The enclaves are generally richer in plagioclase and mafic minerals and poorer in quartz and potash feldspar than the matrix. One type of inclusion is a fine granular rock consisting of biotite, plagioclase, and quartz. A second and more common type is a basic rock similar to the prevalent enclaves in the dioritic rocks described below. The margins of the inclusions are fairly well defined and there is no marginal zone of reaction. Within the limits of large hand-specimens there seems to be no connection between the nature of the enclave and the composition of the matrix. Thus, a biotite-granulite enclave can be found in a matrix containing hornblendic clots, or a basic xenolith in a leucocratic granite.

The *dioritic types of xenolithic rock* range from dark hornblende-rich varieties to pale grey rocks which pass into the xenolithic granites already described. The inclusions are fairly well-defined and show no reaction zones. The chief constituents of the matrix are oligoclase, quartz, hornblende, and biotite with accessory apatite, iron oxide, sphene, and orthite; potash feldspar may form up to a third of the total feldspar, but is often completely absent; its variations seem independent of those of the other minerals. A pale green granular clinopyroxene is occasionally present.

Although the textures show great variation, ranging from finely granular to an almost appinitic appearance, there are certain features which are common not only to most varieties of the matrix but also to the enclaves. The slightly zoned plagioclase forms subhedral laths set without orientation in a matrix composed of mafic minerals, quartz, and orthoclase. Biotite and hornblende are usually ragged and often enclose euhedra of plagioclase smaller than those in the rest of the rock; the plagioclase shows its crystal outline against its hosts and was evidently half-grown when they recrystallized. Quartz and potash feldspar, when this is present, either form interstitial grains or coalesce into pools up to 4 mm. across which extinguish simultaneously throughout their extent; within these pools lie plagioclase laths and mafic crystals with exactly the same form as those whose matrix is granular.

The enclaves in the dioritic rocks are characterized by abundance of hornblende and some contain in addition a pale green granular clinopyroxene. The minerals present are the same as those in the

matrix, mafic minerals being more abundant, quartz rather less so, and potash feldspar very variable. The textural features of the dioritic matrix described above are displayed also in the enclaves. The lath-like form and random orientation of the plagioclase are the same, but the crystals are generally smaller than those of the matrix. Hornblende and biotite can be seen enclosing euhedral plagioclase crystals smaller than those in the rest of the rock. Orthoclase, when present, and quartz form large pools filling the microscope field under the 1-inch objective and enclosing multitudes of small euhedra of all the other components, these being arranged in a perfectly random manner; the enclosed hornblendes themselves contain still smaller plagioclase crystals.

Analyses of two quartz-diorites and of a basic inclusion from a quartz-diorite are given in Table I.

Discussion

The distribution in the field of the various rock types described above suggests that they are all related, since patches of granite or syenite occur within quartz-diorite and vice versa, and since transitional types can be observed. The fact that the quartz-diorite is almost always xenolith-bearing and that the enclaves consist of more basic material may provide the key to its origin. The textures of the enclaves, as has been seen above, are complex and the same complexities are carried through into the dioritic matrix. A prolonged sequence of crystallization, such as might result from reaction between the magma and its inclusions is thus recorded. Moreover, the diorite contains in addition to the actual inclusions abundant small knots of hornblende and biotite. There is therefore considerable evidence to suggest that the magma producing the diorite reacted with, and was modified by, its inclusions; the uncontaminated magma was presumably the source of the granitic and syenitic parts of the complex.

In their macroscopic and microscopic characters, the Insch quartz-diorites are very similar to rocks described by Nockolds (1931, 1932, 1933, 1934) from the Isle of Man, Loch Awe, and Bibette Head, Alderney, by Wells and Wooldridge (1931) from Jersey and Deer (1935, 1938) from the Cairnsmore of Carsphairn complex in Galloway and from Glen Tilt in Perthshire. In all these cases the dioritic rocks are shown to have resulted from the contamination of granitic magma with basic igneous material, the processes operating being those of reciprocal reaction and mechanical disintegration. During reciprocal reaction, FeO, MgO, and CaO pass into the magma from the basic enclaves which receive in exchange alkalies and perhaps Al_2O_3.

In Table I are given analyses of the Insch granite, the quartz-diorites, and an enclave in the latter, together with relevant analyses from the

Isle of Man and Cairnsmore of Carsphairn complexes. The source of the basic inclusions in the Insch quartz-diorites is not known, but it may well have been the hypersthene-gabbro of the Insch mass, with which the granite-diorite complex is in contact along most of its eastern margin, or some related rock. An analysis of the hypersthene-gabbro is therefore also given.

Comparison of the hypersthene-gabbro analysis with that of the basic enclave shows the latter to be poorer in FeO and CaO than the former, and richer in alkalies, especially in potash; MgO is almost the same in both rocks. Comparison of the granite with the quartz-diorite analyses indicates that the granite magma lost SiO_2 and alkalies, and gained Al_2O_3, FeO, MgO, and CaO during contamination. These changes agree in a general way with those demonstrated from the other granite-gabbro complexes. If the hypersthene-gabbro is the source of the basic enclaves, then its modification by reaction with the granite magma also follows the same course as that of basic inclusions in the other complexes.

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GEOLOGY DEPARTMENT,
IMPERIAL COLLEGE,
LONDON, S.W. 7.

The Structure of the Granophyric Quartz-Dolerite Intrusion of Centre 2, Ardnamurchan and the Problem of Net-Veining

By M. K. Wells

Abstract

The Quartz-dolerite intrusion of Sgùrr nam Meann, Ardnamurchan, is shown to be a ring-dyke which has sill apophyses extending from its outer wall. This is a form of intrusion which has not been recognized before, and its field relations are described in detail. The quartz-dolerite is extensively veined by acid rocks which are ubiquitous in all parts of the intrusion, and most abundant in the sills. From the evidence of the distribution and nature of the veining it is concluded that the acid and basic components of the intrusion must have been emplaced simultaneously. It is suggested that a gas-charged, acid residual magma may have separated from a crystallizing basic parent under the influence of sudden reductions of external pressure acting upon the system.

Introduction

THE close association of granophyre with gabbro or dolerite is a widespread phenomenon in the British Tertiary volcanic province and elsewhere. It is manifest in a variety of ways: as separate, though neighbouring major intrusions of gabbro and granophyre (e.g. in Skye and Mull); as composite sills and dykes; and as gabbro or dolerite intrusions which are riddled with intersecting networks of granophyre veins. All of these occurrences provide problems that have been only partially solved. In the first place, the very close space and time relations of the two kinds of intrusive material (acid and basic) have to be considered. Secondly, there is the problem of the contrasted composition of the dominant rock types with inadequate representation of intermediate rocks. In the case of the net-veining an added complication is provided by the mechanism of the veining and of the extensive brecciation of the host rocks.

The phenomenon of net-veining therefore touches upon a number of important petrological problems and it is very desirable that the field relations of any well-exposed examples should be adequately known. The granophyre-veined Quartz-dolerite intrusion of Sgùrr nam Meann, Centre 2, Ardnamurchan, is particularly suitable for such a study, since not only are the vein-complexes excellently displayed in extensive shore exposures, but the unusual shape of the intrusion provides a useful degree of control over the range of speculation regarding the veining mechanism. It is necessary to know the shape of the intrusion in order to appreciate much of the significance of the veining.

Structure of the Quartz-Dolerite Intrusion

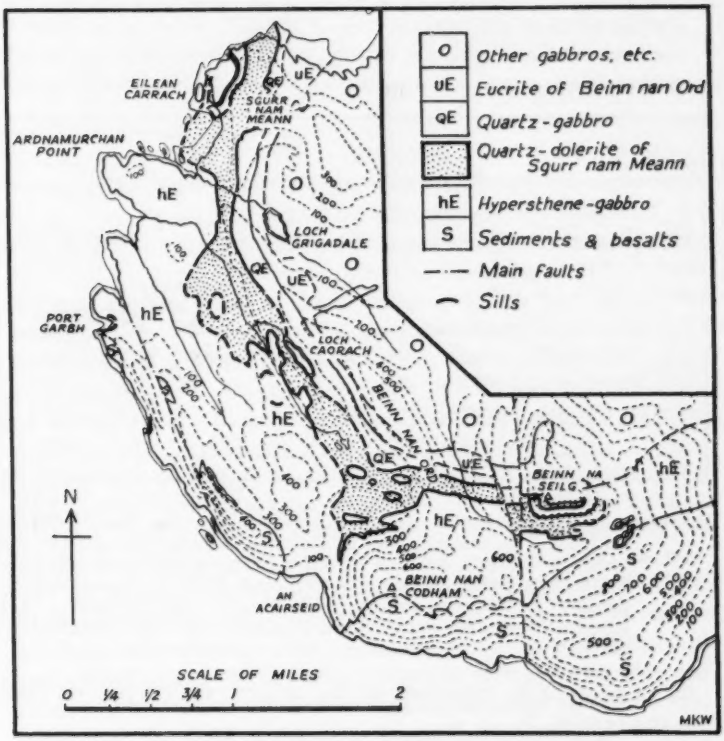
Examination of the geological map of the area (Sheet 51 of H.M. Geol. Survey, cf. Text-fig. 1) shows the outcrop of the Quartz-dolerite ring-intrusion to be of very irregular shape. A distinction must be made between the outer and inner margins of the intrusion. The former is a very sinuous one formed by the intrusive contact of the Quartz-dolerite against the earlier Hypersthene-gabbro intrusion. The latter is a smoothly curving junction where the Quartz-dolerite is itself cut by a later Quartz-gabbro ring-dyke. The Quartz-dolerite may originally have been somewhat wider than the present outcrop, though probably not to any great extent, and for all that is known to the contrary, the original inner wall of the intrusion may have been as irregular as the outer one.

Our ultimate object is to decide the cause of the irregularities of the outer margin; but first it is desirable to stress certain similarities between the form of the Quartz-dolerite intrusion and that of the two neighbouring ring-dykes, the Quartz-gabbro and Eucrite shown in Text-fig. 1. Although the width of the Quartz-dolerite outcrop varies greatly along its length there are three localities (west of L. Grigadale, west of L. Caorach, and due west of Beinn na Seilg summit) where it is reduced to a minimum which is quite comparable with the widths of the two adjacent ring-dykes. If the widenings in between these localities are ignored it is seen that all three outcrops are remarkably parallel. The actual contact between the Quartz-dolerite and the Hypersthene-gabbro is exposed in a cliff-like feature at one point, and is illustrated in the *Ardnamurchan Memoir* (p. 259, fig. 35). It is a steep (65°–70°), outwardly-dipping contact as in other Hebridean ring-dykes; and in fact all the characters noted in this paragraph serve to emphasize that the inner part of the intrusion is a true ring-dyke and one of a family of three closely related ring-structures (*Ardnamurchan Memoir*, p. 255).

It is obvious from the map that the only parts of the outer margin whose positions were controlled by a ring-fracture system are those shown by the heavy outline in Text-fig. 1. The nature of the remaining irregular contact can now be viewed in its proper perspective: *the unusual shape is due to the occurrence of flat or very gently inclined sheets of the Quartz-dolerite veined by granophyre which form apophyses to the main ring-dyke.* Since this is the first time, to the writer's knowledge, that a ring-dyke/sill intrusion has been described, the field occurrence will be described in some detail.

(1) *Beinn na Seilg.*—The outcrop of the Quartz-dolerite forms a curiously shaped double-pronged loop around the steep southern face of the hill, much as shown on the Geological Survey maps

prepared by Dr. Richey. Mapping on a large scale with the invaluable aid of good aerial photographs, the writer has been able to modify the map slightly and to re-interpret the structure. In a cross-section of the area illustrated in the *Memoir* (p. 219) the Quartz-dolerite is depicted as steeply dipping. In actual fact the northern loop of the outcrop partially encircles the hill top, following a contour

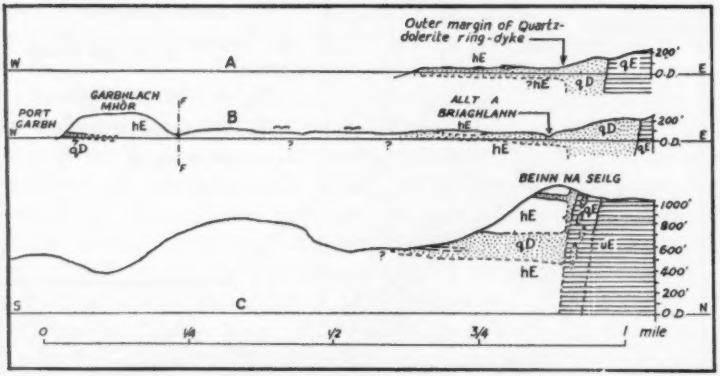


TEXT-FIG. 1.—Map of the quartz-dolerite of Sgùrr nam Meann.

about a hundred feet below the summit. The outcrop is a slender one which can be traced even from a distance due to the fact that the granophyre veins which are ubiquitous in the Quartz-dolerite, weather easily to form a line of small screes. The actual upper contact with the Hypersthene-gabbro is visible at a number of places and is generally flat lying. The lower contact is not exposed; but it seems probable that the thickness of this Quartz-dolerite sheet is about 30 feet. The lower, southern outcrop is broader, but it extends into the valley in which the twin lochs lie (see Text-fig. 1) and exposures

are poor, so that the exact shape of the outcrop is doubtful. However, the general parallelism of the two outcrops suggests that the lower one is also produced by a sheet-like mass of the Quartz-dolerite (Text-fig. 2).

The upper and lower sills of Quartz-dolerite must have been fed from part of the main ring-dyke, remnants of which can still be found on the west-facing slope of Beinn na Seilg and in an east–west col just north of the twin summits of the hill. Most of the dyke has been cut out here by later intrusions, and in particular by the Quartz-gabbro which contains numerous inclusions of finer grained dolerite



TEXT-FIG. 2.—Diagrammatic sections drawn across the Quartz-dolerite intrusion: A, through Port na Caraidh, the inlet one-quarter mile south of Eilean Carrach; B, Port Garbh to Allt a Briaghlann; C, through Beinn na Seilg. Rocks older than the Quartz-dolerite (mainly Hypersthene-gabbro, hE) white; Quartz-dolerite, qD, stippled; younger rocks (Quartz-gabbro, qE, and Eucrite, uE) ruled.

that are probably fragments of the original Quartz-dolerite ring-dyke (Text-fig. 2).

(2) *Valley between Beinn nan Ord and An Acairseid.*—A comparison of the Geological Survey map of Dr. Richey with the author's map (Text-fig. 1) shows that for this area (and only for this area) the two interpretations of the position of the Quartz-dolerite/Hypersthene-gabbro contact are essentially different. The line drawn on the Survey map follows roughly the position of a number of isolated outcrops of Hypersthene-gabbro which form small mounds in an otherwise low-lying area of Quartz-dolerite veined by granophyre. The extension of the Quartz-dolerite south-west of the line of Hypersthene-gabbro outcrops would normally not be suspected, especially if the prime object of the survey were the tracing of a ring-dyke margin. The main contact can actually be followed

without any appreciable break from the southern end of Beinn nan Ord (where the junction is steeply inclined, i.e. appropriate to a ring-dyke) to the southernmost point of the intrusion near the An Acairseid inlet, where the Quartz-dolerite forms a very prominent sill. This is probably the most critical part of the whole Quartz-dolerite outcrop from a structural aspect, since it provides a direct connection between the excellent exposure of a ring-dyke contact, illustrated in the *Ardnamurchan Memoir* (p. 259, fig. 35), and the equally well-exposed sill which is recessed into the base of a steep cliff feature of Hypersthene-gabbro.

(3) *West of Loch Caorach.*—As shown on the Survey map and confirmed by the author, the Hypersthene-gabbro forms two lobes, one on either side of the Allt a' Briaghlann which flows in a narrow steep-sided valley. On a closely contoured map the significance of the form of the outcrops would be immediately apparent: the Quartz-dolerite forms a sharp " V " projecting up the valley, and the flanking lobes of gabbro occur on twin spurs. The contact between the two rocks is therefore sensibly flat, with the gabbro overlying the dolerite. A further significant point to note is the occurrence of a granophyre sill which occurs a few feet above this contact on the western spur. Sills of a similar type are found at various points along the western cliffs, cutting the Hypersthene-gabbro. Their significance is discussed below.

(4) *Ardnamurchan Point—Eilean Carrach.*—The outcrop of the Quartz-dolerite broadens out to include the area of the foreshore north of Ardnamurchan Point. The actual relationships of the Hypersthene-gabbro, the dolerite and associated granophyre could only be shown at all adequately on a very large scale plan for they are extremely complex. All the rocks forming the extensive foreshore between Ardnamurchan Point and Eilean Carrach are riddled with granophyre veins. We are only concerned with essential facts concerning the form of the Quartz-dolerite intrusion in this locality, which may be stated as follows: the contact between the dolerite-granophyre complex and the Hypersthene-gabbro is nearly horizontal and corresponds to the present level of erosion of the wave-washed rock platform. Fragments of the overlying gabbro project as isolated blocks above this general level, much in the manner of outliers. As in the last case described above, the main contact is overlain by a granophyre sill which is shown on the Survey map with bifurcation at its southern end.

Dolerite-granophyre Sills isolated from the main Intrusion

A curious and hitherto unexplained feature of the Hypersthene-gabbro outcrop is the frequent recurrence within it of acid sheets or

sills which have no obvious feeders or connection with any other intrusions. They are always associated with features of negative relief due largely to the easy breaking down of the " granophyre " which has a closely spaced polygonal jointing and is, in consequence, the best scree-forming rock in western Ardnamurchan. Nine of these acid sheets have been recorded by the writer (Text-fig. 1), four of them occurring at, or near to, sea-level along the base of the cliffs between Ardnamurchan Point and the inlet of An Acairseid. Due to the easy erosion their outcrops tend to be recessed, sometimes to form actual caves, and this has largely controlled the shape of the coastline in this region. Clearly the four coastal occurrences are closely related to one another and they may even be the interrupted outcrops of a single sheet. In one instance (the Port Garbh sill) the granophyre is associated with dolerite in a manner that is highly characteristic of the main Quartz-dolerite intrusion. The relationship of the two rock-types in the Port Garbh sill is described below (p. 301); but at this point the relationship may be said to be so distinctive that it provides strong grounds for believing that the sill has been fed from the same source as the main intrusion. If this argument applies to one member of the group of sills outcropping along the coast, it is reasonable to extend it to all of them.

Distribution of Acid Veins in the Quartz-dolerite

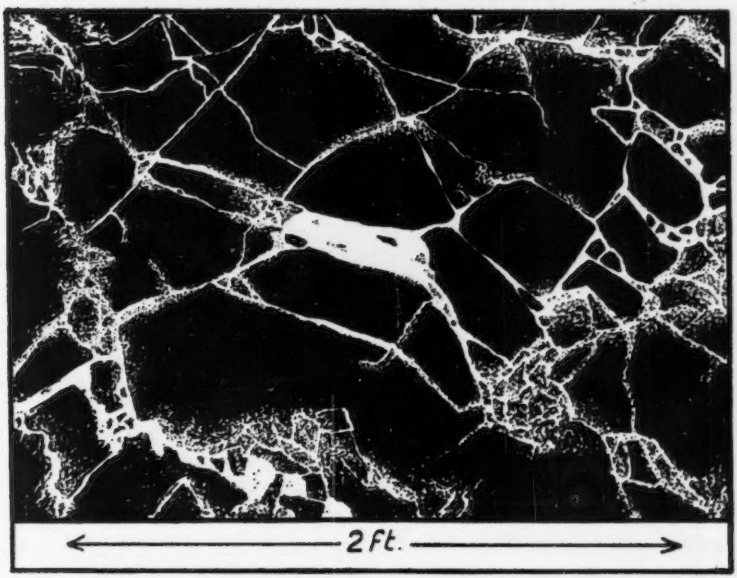
Acid veining on a small scale is quite a normal feature of the marginal parts of several gabbro intrusions of Ardnamurchan and elsewhere; but the concentration of granitic material within the Quartz-dolerite is quite exceptional. It is widespread and not confined merely to the outer margin of the intrusion. Only one other intrusion in Ardnamurchan shows the same features. This is a slender ring-dyke of the Centre 3 Complex (*Ardnamurchan Memoir*, p. 327). The following description of the net-veining might equally apply to either intrusion.

The degree of concentration and the style of acid veining vary from point to point in the Quartz-dolerite intrusion. One cannot travel more than a few yards anywhere within the outcrop of the latter without finding a plexus of veins, each one covering something of the order of a hundred square yards of outcrop. The distribution of these networks is quite random as far as can be judged. There is no sign of any major feeding channels, nor is there evidence of a linear distribution of the complexes such as one might expect if the injection of the acid material were guided by a fissure system similar to that responsible for the location of the ring-dyke itself.

In the ring-dyke part of the intrusion the characteristic form of acid injection is true *net-veining*. The structure is similar to that of " crazy-paving ". The polygonal dolerite blocks are from a few inches

to about 2 feet in width, separated by parallel-sided acid veins generally less than 3 inches in width (Text-fig. 3). The dolerite blocks are quite obviously displaced by the thickness of the acid veins, and in the absence of the latter, would fit together like a jig-saw.

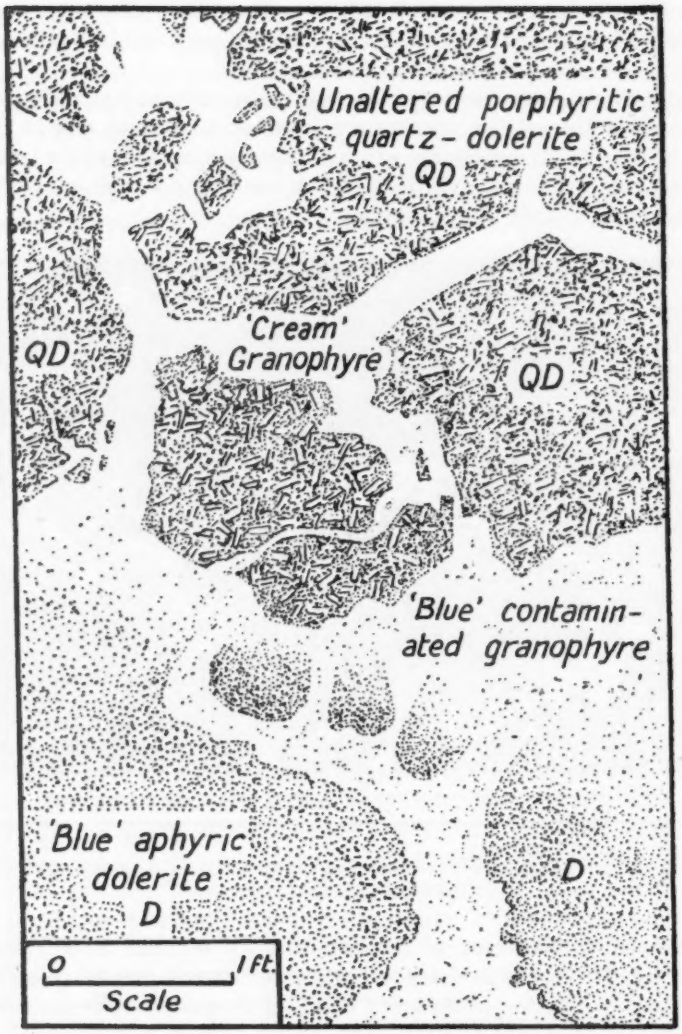
It is important to note that the total volume of acid material represented in the net-vein complexes is small in relation to that of the host dolerite. It is probably only a fraction of 1 per cent of the latter. Nowhere in the ring-dyke part of the intrusion does the local concentration of acid rock become great.



TEXT-FIG. 3.—Diagram of net-veining at Eilean Carrach. Quartz-dolerite is shown black; granitic veins white.

In the sill apophyses of the ring-dyke the situation is different, and locally the amount of granophyre may exceed that of dolerite. Because of the easy weathering of the granophyric rocks and the frequently poor exposure of many of the sill-like portions of the intrusion it is difficult to make safe generalizations regarding the relative proportions of the acid and basic rocks. It seems, however, that *granophyric rocks are concentrated towards the roofs of the sills* (*e.g. Beinn na Seilg, p. 294; An Acairseid, p. 296*); *and they increase in amount towards the outer extremities of the sills away from the feeding ring-dyke.*

Naturally, with variation in the proportions of the acid and basic



TEXT-FIG. 4.—Field sketch illustrating the rapid changes in style of veining and composition of the acid and basic rocks occurring within a small exposure. Port na Caraidh, one-quarter mile south of Eilean Carrach. Note "jig-saw" fit of displaced dolerite shown at the top of the diagram, and the crenulate junction between acid "dolerite" and basified "granophyre" at the bottom.

rocks, their mode of occurrence varies. When both are present in roughly equal amounts, their mutual boundaries often tend to be crenulate (Text-fig. 4, lower part), and the granophyre occurs in irregular masses rather than well-defined veins. When the acid rock is predominant, rounded fragments of dolerite may be enclosed as xenoliths. Occasionally, as at Eilean Carrach, xenoliths of a variety of basic rocks (gabbro, porphyritic, and non-porphyritic dolerites, basalt, and pyroxene-granulites) in different stages of acidification and rounding occur together in a matrix of granophyre. This proves that under certain conditions in the sills, granophyre magma had free mobility and was able to collect up an assortment of stoped rocks lying in its path. These features can all be seen in the dolerite/granophyre sills which are demonstrably attached to the main part of the intrusion. They are all (including true net-veining) displayed to excellent advantage in the wave-cut platform of the bay south of Eilean Carrach. It is from this area that most of the details of the granophyre/dolerite relation were noted and many of the specimens collected.

It requires little extrapolation of these observed facts to cover the phenomena found in the several sills whose outcrops are isolated from the main intrusion (p. 297). All that is required is a further increase in the proportion of acid material. These outcrops lie at appropriate levels (O.D.) to be apophyses of the main intrusion. They are predominantly " granophyric ", although in one most significant case (the Port Garbh sill, p. 298) " dolerite " and " granophyre " are both found in about equal amounts and displaying the highly characteristic crenulate junctions noted above (compare Text-fig. 5).

In all the occurrences the granophyre-dolerite junctions tend to be sharp (*Ardnamurchan Memoir*, p. 257), although gradations into dark " granophyre " or pale and acidified " dolerite " are not uncommon. These mixed rocks may themselves unite along sharp contacts (Text-fig. 4).

Origin of the Acid Veining

In the *Ardnamurchan Memoir* (p. 257) it is stated that: " the consolidation of the quartz-dolerite was complete before its brecciation and the injection of the granophyre . . ." and from this it is concluded that the granophyre magma was intruded distinctly later than the quartz-dolerite and that it rose within the same ring-fissure as the latter.

In any geological problem it is logical to give greatest weight of consideration to the major facts of field distribution before turning to more detailed points of structural or textural relations. In this case one of the major facts, namely the shape of the main intrusion, has been reinterpreted by the writer, and this has a critical bearing upon the

problem of the origin of the acid veining. The major facts to be taken into account are considered to be:—

(1) The complex shape of the Quartz-dolerite intrusion;
(2) the ubiquitous distribution of veins of acid rocks in all parts of the latter; and
(3) virtual absence of similar veins in the adjacent Hypersthene-gabbro.

On the basis of these facts it can be established that the quartz-dolerite and granophyre are closely and uniquely related in regard to both the time and mode of their emplacement. If the form of the Quartz-dolerite intrusion were that of a simple ring-dyke, then it is just conceivable that a later veining by granophyre magma might have been confined to the limits of this one intrusion, perhaps due to the existence of a higher temperature and consequently greater ease of penetration of the quartz-dolerite compared with the adjacent Hypersthene-gabbro, at the time of acid veining. Even under these conditions it is hard to picture a process of later injection which could give the veins such a widespread distribution throughout the whole intrusion; and to do it, incidentally, without the aid of any visible feeding channel to link up the scattered vein complexes.

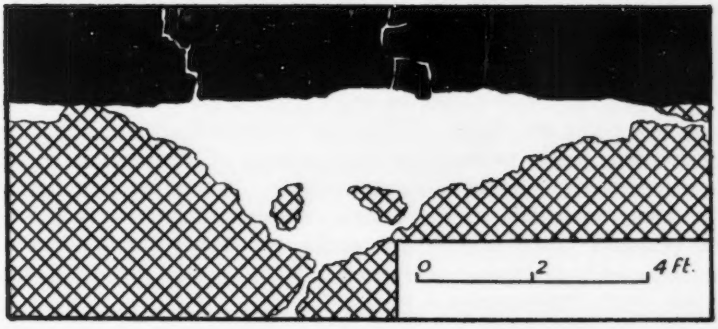
The Quartz-dolerite intrusion actually has a very complex shape, as described in the first part of this paper. For all parts of such a body to be penetrated by later granophyric material (and for the latter to become concentrated towards the roofs and extemities of the sills, as seems to be the case) would require a very improbable degree of special conditions to operate. There seems no escape from the conclusion that *the granophyric material was emplaced in some form essentially at the same time as the main quartz-dolerite magma was intruded.*

In some parts of the sills (e.g. at Port Garbh and An Acairseid) there is direct evidence which supports this conclusion. In the An Acairseid sill, for example, both the granophyre and quartz-dolerite combine to form a single straight (fracture-guided) contact with the roof of Hypersthene-gabbro. The dolerite/granophyre contacts, however, are intricate and crenulate (Text-fig. 5). The complete significance of crenulate junctions in these rocks is not known: it is probably a feature produced when both the materials of the dolerite- and granophyre-to-be were in a semi-molten, plastic condition. However this may be, it is certain that there was only one main episode of intrusion in which both the granophyric and doleritic materials were involved, both temporarily in a similar physical condition, and that the Hypersthene-gabbro functioned as their rigid container.

Not only do the space considerations seem to demand essentially simultaneous emplacement of the acid and basic components of the Quartz-dolerite intrusion; but consideration of the thermal energy

involved points to the same conclusion. (For a detailed discussion of the heat problems associated with intrusion, see Graton, 1945.)

The true net-veining (p. 298) involves innumerable slender veins separating blocks of quartz-dolerite. The vein-rock is unchilled. The granophyre magma seems to have dissipated rather than conserved its thermal energy. Instead of forming a few fissure-guided dykes it has penetrated the quartz-dolerite in an intricate network of small veins (rarely more than an inch across), which must have provided an



TEXT-FIG. 5.—Field sketch of relationships of hypersthene-gabbro (black), quartz-dolerite (ruled), and granophyre (white) against the roof of the Beinn nan Codham (= An Acairseid) sill.

enormous cooling surface in relation to the volume of granophyre magma available. The veins are of a dilation type so that the magma not only had to overcome conductional cooling but also the energy loss due to expansion against the shattered dolerite. In a plutonic environment the widespread distribution of slender, unchilled granitic veins is very simply explained by assuming the country rock to be at the same temperature as the injected material. The same consideration must apply in the present case, although it should be noted that this is an exceptional condition in a volcanic environment where sharp temperature gradients are the normal order. In the case of the granophyre veins in the Quartz-dolerite intrusion we must conclude that the vein material did not lose an appreciable quantity of heat to the surrounding quartz-dolerite and that there was essentially thermal equilibrium between the two components of the system. The main heat reservoir of the whole system would have been the quartz-dolerite component on account of its predominant volume and heat-capacity.

If the acid and basic components of the Quartz-dolerite were simultaneously intruded, as the distribution of the vein-complexes strongly suggests, then there remains the problem of the formation of sharply-defined veins under these conditions. Until quite recently the

occurrence of any cross-cutting vein was considered proof in itself that the rock in the vein was distinctly younger than the rocks around it. Several instances are now known, however, in which the host-rock provided the energy and motivating power for the formation of cross-cutting veins. Good examples are provided by some of the granitic veins which cut dolerite sills in the Karoo, South Africa (Walker and Poldervaart, 1948, p. 614). The source of some of the veins can be traced back to sedimentary inclusions within the dolerite, which have caused heating up and metasomatism of the xenoliths to the point where the latter had sufficient mobility to inject the solidifying dolerite. The writer has described a small-scale example of a similar phenomenon in Ardnamurchan (Wells, 1951, p. 720).

In every case of this kind the rocks forming the veins are acid and the host-rocks are basic. This must necessarily be so, since the phenomena is due to the lower melting range of temperatures of the acid compared with the basic components. It has been recognized for many years that under plutonic conditions there are ranges of temperature within which basic rocks may behave as rigid components while juxtaposed acid material is highly fluid (see e.g. Sederholm, 1926). This concept is less familiar in its application to volcanic rocks; but the writer believes that the phenomenon of net-veining of the Sgùrr nam Meann intrusion is one instance to which it should be applied.

In the foregoing discussion the writer has been cautious in the manner of describing the dolerite and granophyric " materials " prior to their consolidation. Too frequent use of the term " magma " might be taken to imply that the quartz-dolerite and granophyre were originally intruded as two fluid, immiscible magmas. A certain degree of immiscibility may occur in silicate melts at very high temperatures; but this condition has certainly disappeared by the time crystals begin to form (Fenner, 1948). In the present case, where comparable crystalline phases (quartz and alkali feldspar) are found in both rocks, chemical immiscibility must be ruled out of consideration.

It is still possible for very rapid intrusion and chilling to prevent the physical mixing of two contiguous magmas. The acid magma may have been produced either by differentiation or palingenesis in depth; or it may have split away from a basic parent actually during the process of intrusion. There is some evidence that the latter alternative is nearer the truth than the former. In the first place the composition of the quartz-dolerite is genetically related in some way to that of the granophyre as shown by the exact duplication of these rock types and their relationship in the other granophyre net-veined quartz-dolerite ring-dyke of Centre 3, Ardnamurchan; and indeed by the

fact that in composite intrusions generally the basic rock is either of quartz-dolerite or tholeiite composition (Kennedy, 1933).

Secondly, the random scattering of the vein complexes and the limited quantity of acid rock in any one part of the ring-dyke suggests that only a limited quantity of granophyric material was present in any given volume of quartz-dolerite. This is readily explainable if both rock types were ultimately differentiates of a common magma.

Any splitting that took place must have occurred when crystallization was far advanced. Grout (1926) has shown by calculation that a granitic residuum can only arise after about 90 per cent (fractional) crystallization of a gabbroic magma. The mechanical difficulties involved in the separation of a residual liquid from such a framework of intergrown crystals have been discussed by Holmes (1936) who has shown that squeezing or " filter pressing " is not a mechanism that is normally applicable in the formation of volcanic rocks.

A reasonable alternative is discussed below.

The Rôle of Gases and Differential Pressures in the Formation of Net-veining

Emmons (1940) has suggested that residual and interstitial liquids may be withdrawn from a crystallizing mass by a reduction of the external pressures being exerted upon the system, with a resulting dilatency of the latter and migration of the still fluid components to parts of the system having a reduced pressure. Emmons has proposed this as a possible explanation for a number of phenomena including granitic veins in gabbros. The present writer believes that the hypothesis is particularly appropriate in the case of net-veining. An essential feature of the concept is the local derivation of the material filling these veins. (This is a widely recognized feature of aplitic and pegmatitic veins in plutons.) Veining produced by dilation would be expected to occur in all parts of the intrusion where local physical conditions were appropriate; but very little of the acid magma would be able to penetrate far beyond the confines of the intrusion. The small size of individual veins and the total volume of granophyre in a vein complex would be controlled by the limited amount of residual magma of appropriate composition available in the host rock crystallizing in the vicinity. The hypothesis provides a reasonable explanation for the presence of a " granophyric " mesostasis in the quartz-dolerite which is similar in composition to the vein rocks.

An outstanding feature of the granophyres is the predominance of hydroxyl-bearing chlorite and amphibole over pyroxene, suggesting that the granophyre crystallized from a relatively low-temperature magma rich in dissolved volatiles, particularly water. This concentration of water, etc., probably gave rise to a separate gas phase especially

as the Quartz-dolerite ring-dyke was almost certainly a near-surface intrusion subject to a relatively low external pressure. Crystallization of the granophyres may actually have raised the vapour pressure of increasingly volatile-rich residua to explosive proportions (cf. Goransen, 1938), giving rise to explosive brecciation of the quartz-dolerite (Richey, 1940). A gas phase would be particularly sensitive to any pressure changes such as those produced by dilatency, and gases probably aided the easy migration of the residual liquids from one part of the crystallizing mass to another.

Recently D. L. Reynolds (1950) has attempted to explain net-veining in terms of intrusive acid tuff lubricated and transported by abundant streams of gas. The broken, and slightly displaced, blocks of dolerite are compared with phenomena displayed in the Swabian tuff-pipes and described by Cloos. As suggested above, gases may well be propulsive agents under suitable pressure and temperature conditions; but a thorough-going hypothesis relying solely upon gas-streaming will not explain the distribution of the vein-complexes in the peculiarly shaped Quartz-dolerite intrusion of Sgùrr nam Meann, nor their restriction to one particular host rock. The writer has been able to find no petrographic evidence that the Ardnamurchan granophyre veins may have solidified from intrusive tuff.

Gases, then, are considered to be the natural accompaniments and possible aids to the formation of net-veining; but the ultimate cause is regarded as the spasmodic release of external pressure applied to the system of crystallizing quartz-dolerite during intrusion of the latter. A major release of pressure would occur if the intrusion broke through to the surface; but the phenomenon of ring-faulting, and in the present case, the opening up of the sill-apophyses to the main intrusion would have been adequate to supply the trigger mechanism of dilatency.

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DEPARTMENT OF GEOLOGY,
UNIVERSITY COLLEGE,
LONDON.

The Loess of Pegwell Bay, Kent, and its Associated Frost Soils

By W. S. Pitcher, D. J. Shearman, and D. C. Pugh

(PLATE VII)

Abstract

The brickearth of Pegwell Bay in Kent is identified as a true loess. It rests on solifluction deposits and frost-shattered rocks.

Introduction

SUPERFICIAL deposits of brickearth occur in East Kent as narrow belts along the bottoms, and as irregular spreads on the sides of valleys eroded in the Chalk and Eocene beds. The distribution of these deposits in Thanet has been recorded in detail by the officers of the Geological Survey (1928) who, with reservations, suggest that some have an aeolian origin.

A study of the brickearth which forms the upper part of the sea cliff extending from Cliffsend towards Pegwell, a locality south-west of Ramsgate, clearly shows that this particular deposit is a true loess; further, this loess rests unconformably on rocks which have been disturbed by a process of freezing and thawing. At Cliffsend the loess overlies Thanet Beds (Eocene), and continuing towards Pegwell it covers the Tertiary-Cretaceous unconformity and crosses on to the Chalk. Along part of the section it rests on Pleistocene gravels and loams which locally fill a broad channel cut into the Chalk. These general relationships are illustrated by fig. 11 of the Geological Survey Memoir on the Ramsgate and Dover area (loc. cit., p. 50).

The clearest section in the loess occurs at Cliffsend where the details recorded below are very little changed over 300 yards of uninterrupted exposure.

II. The Characteristics of Loess

Before describing the Pegwell Bay occurrence in detail we refer to R. J. Russell (1944) for the characteristics of undoubted loess deposits; in listing them we are not unaware of the varied opinion on the origin of loess which follows upon its definition. The essential criteria given by Russell are as follows:—

(1) Characteristic grain-size frequency distribution. At least 50 per cent of the particles have sedimentation diameters between 0·05 and 0·01 mm.

(2) Colour, yellowish to buff, although red varieties are known.

(3) Generally structureless, rarely showing bedding or lamination.

(4) Strong tendency for exposures to maintain vertical faces, despite

the lack of cementation which is shown by the fact that loess may be disaggregated between the fingers, and falls apart in water.

(5) Vertical prismatic jointing.

(6) Normally calcareous, with a well-defined upper leached (non-calcareous) zone.

(7) Presence of tiny calcareous tubular concretions, often enclosing the remains of roots and rootlets. These rootlet tubes are very conspicuous in the unleached zone.

(8) Abundant irregularly shaped hollow calcareous concretions especially in the lower part of the leached zone.

(9) Common occurrence of gravels or pebbly bands in the lowest part of the deposit.

(10) Terrestrial fauna, mainly of land snails.

III. The Loess at Cliffsend in Pegwell Bay

The " brickearth " at Cliffsend exhibits all these criteria. Plate VII shows the deposit 12 ft. 6 in. thick, with a discontinuous band of scattered flint pebbles in its lowest part, resting unconformably on the Thanet Beds (line B). On the vertical face of the exposure the prismatic jointing is well seen, and this shows its most perfect development in the leached zone below the modern soil.

The boundary between the slightly darker upper leached zone, and the lower lighter-coloured calcareous zone is abrupt (line A), the acid-soluble material falling sharply from 25 per cent to less than 5 per cent across the line of colour change. The presence of worn Upper Chalk foraminifera in the unleached zone suggests that much of the calcareous material, which is seen under the microscope to occur as discrete grains of calcite, is derived from the Chalk. Small calcareous rootlet tubes about $\frac{1}{20}$ inch in diameter are abundant throughout the unleached zone. Larger concretions, up to 1 inch across, are especially common near the base, and also occur along with rootlet-tubes which have penetrated the underlying Thanet Beds. These highly calcareous concretions leave an insoluble clay residue on acid treatment and give a mild reaction for phosphate. Many are hollow, with cracks in the cortex narrowing outwards towards the periphery as if produced by the desiccation of a gel.

The loess is largely composed of highly angular grains of quartz with a small proportion of exceedingly thin flakes of white mica. A well-defined suite of heavy minerals bears a strong affinity to that of the underlying Thanet Beds. Mechanical analyses of ten samples from various levels were made, using the pipette methods with sodium oxalate as the dispersing agent. All the samples were first treated with dilute hydrochloric acid and hydrogen peroxide to remove calcium carbonate and organic matter respectively. Cumulative curves of the

size frequency distributions were found to be in agreement with published analyses of loess. (See, for example, Swineford and Frye, 1951.) The percentage of particles having sedimentation diameters between 0·05 and 0·01 mm. (see Table 1) is lowest in samples taken from the base and highest in material from the upper part of the calcareous zone.

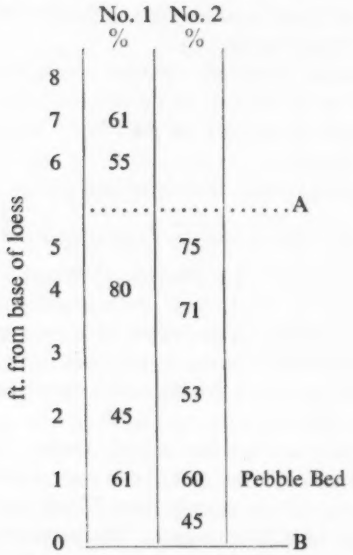

TABLE 1.—WEIGHT PER CENT LYING BETWEEN 0·05 MM. AND 0·01 MM. AT VARIOUS LEVELS

A, base of leached zone; B, base of loess. The two sets of samples are 30 yards apart.

Although a faint colour banding is visible along a limited part of the section, a close inspection fails to show differences in texture and the characteristics recorded above leave no doubt that the brickearth at Pegwell Bay is a true loess.

IV. THE "FROST SOIL" UNDERLYING THE LOESS AT CLIFFSEND

The Thanet Beds, which form a shallow syncline, are dominantly silty marls with two well-defined shell beds (S1 and S2 of Plate VII), and a thin band of fine sand which is locally cemented to form dogger-like concretions. The unconformity between the Thanet Beds and the overlying loess is very clearly seen.

Below the base of the loess, the Thanet Beds are strongly shattered to a depth of 6 to 8 feet. This shattering is purely mechanical, for the rather irregularly jointed marl at the base of the cliff becomes progressively more broken upwards, until at a level a foot or so below the

sharply defined base of the loess, the marl is completely disaggregated and superficially resembles the overlying loess (Plate VII). The unweathered marls are dark blue, but in the zone of shattering they become buff in colour due to the oxidation of iron-bearing compounds. This colour change, which extends to a depth of 15 feet below the base of the loess, was well shown after a heavy winter frost had spalled the superficially weathered material off the cliff face.

Although the broken fragments of marl have been disorientated, there has been no lateral movement of the fragmented material; this is shown by the regular upward decrease in fragment size. Further proof is provided at a point about 40 yards from the end of the section (Plate VII), where two shell bands (S1 and S2) which pass up through the shattered zone to the plane of the unconformity, retain their identity without any change in dip. Although the shells become progressively more comminuted the general outline of the valves remains. The doggers overlying the most conspicuous shell band (S1) are also broken up on the zone of the shattering.

The disturbed upper part of the Thanet Beds on which the loess rests is interpreted as a pre-loess frost soil. The disintegration is due to frost shattering, without any lateral movement of the fragmented material by solifluction.

Wind erosion of the fine materials produced in frost soils of this type could well provide much of the aeolian dust necessary for loess formation. Such a mechanism has been suggested for the formation of loess-like material on Mt. Kenya (Zeuner, 1949).

V. The Orientation of the Pebbles at the Base of the Loess

At Cliffsend, the base of the loess is characterized by irregularly scattered oval black flint pebbles, up to 2 inches in maximum diameter. They do not necessarily occur at the absolute base of the loess, but are scattered within the lowest 12 inches. Locally they are crowded into shallow depressions on the depositional surface.

The pebbles are typically those of the Tertiary Pebble Beds of the London Basin, and were no doubt derived from them. These reworked Tertiary pebbles at the base of the loess are in marked contrast to the solifluction gravels of the neighbourhood, which are characterized by angular broken flints and " bullhead " flints.

The presence of these pebbles at the base of the loess is difficult to explain, but it is possible that they were washed on to the frozen surface of the underlying frost soil by sheet flooding before the loess was deposited. Their scattered occurrences and tendency to be concentrated in shallow depressions on the surface of the frost soil, where they are associated with minute flint chips, supports this contention.

The pebbles show a strongly developed preferred orientation,

tending to stand up on end with their long or intermediate diameters approaching the vertical or inclined at a high angle. A random pebble count showed that over 55 per cent are inclined at an angle of 70° or more. This remarkable orientation cannot be a depositional feature, and can only be explained as a result of frost-heaving, which would also account for the fact that many of the pebbles are found scattered in the loess several inches above the base of the deposit.

The most convincing evidence for frost-heaving during the early stages of the deposition of the loess is shown where a frost-shattered Thanet dogger " outcrops " at the base of the loess. Fragments of this dogger are abundant in the lowest 18 inches of the loess immediately above it, and appear to have been lifted up into the loess without any lateral displacement.

VI. The Extension of the Section North-East towards Pegwell

Half a mile further to the north-east a similar loess occupies the top of the Chalk cliffs. Here it rests on 4–5 feet of chalky sludge which itself overlies chalk shattered to a depth of some 15 feet. The loess again shows a leached zone but it is more generally banded and includes a layer of angular flints at its base. The sludge deposit is largely composed of chalk fragments with elongated irregular pockets or involutions of brown loam; these are often sub-parallel and steeply inclined.

Nearer Cliffsend a similar loess horizon rests on chalky gravels and at one point gravels and loams fill a broad channel cutting well down into disturbed and brecciated chalk. Within this channel festoons of angular flint gravels are separated by a brown loam containing scattered flints. The loam, which exhibits a weak stratification, is much like a loess in texture though slightly greasy in feel. This and other channel infillings are clearly solifluction deposits and the loam is evidently a redistributed loess. It is worthy of note that near the deep channel a distinct black soil horizon tops similar loamy material and immediately underlies the loess.

In many of the solifluction deposits beneath the loess the apices of the festoons appear to be intruding upward and the stones tend to lie parallel to the contact between the beds. Such festoon-like structure or involutions in glacial deposits have received considerable attention and are attributed by most authors to a process of differential freezing and the growth of ground ice, in a seasonally thawed zone overlying perennially frozen ground (Sharp, 1942; Schafer, 1949). It is relevant to note that the latter author refers to the preferred orientation of the long axes of stones in such deposits (loc. cit., p. 158).

VIII. Conclusion

It may be debatable whether loess is always of aeolian origin, though the authors would assign such an origin to the homogeneous, structureless, and highly sorted silt at Pegwell Bay. The source of this material cannot be deduced from such a localized study, but some was clearly derived from the Thanet beds and much of the lime probably originated from the Chalk. The formation of the loess is closely connected in time with the production of the frost soils and solifluction deposits, and frost heaving was in operation during the early stages of deposition. According to Zeuner (1945, p. 81) numerous sections in northern France show that a phase of solifluction preceded the formation of a sheet of loess which in turn was later weathered; this cycle is interpreted as evidence of the change from the conditions of the tundra through steppe to those of the temperate forest.

When the distribution of the loess deposits is followed across Europe the brickearths of S.E. England would appear to be their obvious continuation. Trechmann (1919) has described an occurrence of loess as far north as Durham and more recently Spencer (1953, p. 3) has identified a loess near Ipswich, whilst in several works Zeuner clearly recognizes the presence of loess in Southern England which have not yet been mapped (see, for instance, Zeuner, 1945, p. 64).

Some of the other deposits of brickearth in Thanet have been found to have the properties of loess, but we are well aware that it would be wrong to identify all Kentish brickearths as loesses without individual study. Indeed, many of them show obvious anomalies, but under periglacial conditions we may expect that, beside true aeolian loesses, there will be many which have been moved and reconstituted by solifluction and others transported and redistributed by water; these could easily be confused with a variety of silts and fine sands of a mixed and varied origin. Breuil, quoted by Zeuner (1945, p. 81), notices that precipitation (rain or snow) interfered with the deposition of the loess in northern France more than in other regions and possibly this observation can be extended to southern England. Even so it seems possible that much of the material of these Kentish brickearths originated in the first place by the winnowing of surface rocks comminuted by the complex processes of frost soil formation.

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DEPARTMENT OF GEOLOGY,
IMPERIAL COLLEGE,
LONDON, S.W. 7.

EXPLANATION OF PLATE VII

A view of the low cliff 30 yards N.E. of the end of the sea wall at Cliffsend, Pegwell Bay, Kent. The prismatically jointed loess clearly shows an upper and darker leached zone and overlies frost-shattered Thanet Beds at level B. There is a decrease in brecciation with depth. Full reference to this section is made in the text.

LOESS OVERLYING FROST SHATTERED THANET BEDS.

The Hypostome of *Encrinurus variolaris* and its Relation to the Cephalon

By J. T. Temple

Abstract

The hypostome of a specimen of *Encrinurus variolaris* (Brongniart) from the Wenlock Limestone (Silurian) is described with particular reference to the intricate shape of the lateral wing. This lies very closely underneath the axial furrow of the cephalon in the region of the anterior pit, but it is unlikely that there was a direct articulation of the wing with the pit or the furrow during life.

THE original of Brongniart's figure of *Encrinurus variolaris* (1822, p. 14, pl. i, fig. 3B–*non* 3A), although possibly still extant, has not yet been discovered, and our interpretation of this species and most of our knowledge of its morphology are due to the work of Fletcher and Salter. The hypostome was figured by Fletcher (1850, pl. xxxii, fig. 9*a*) from a specimen which has been identified by Mr. R. Baker in the British Museum (Natural History) (registered number In 46460) but the lateral wings of the hypostome are not exposed in this specimen, and their structure has never been described fully. The following description is based on a specimen from the Wenlock Limestone of Dudley belonging to the Sedgwick Museum (registered number A 28444), which I have been able to study through the courtesy of Mr. A. G. Brighton. It consists of the cephalon [1] and hypostome apparently in their natural relative positions and, as is usual with Dudley forms, preserving the substance of the test. It was originally covered to a large extent by matrix.

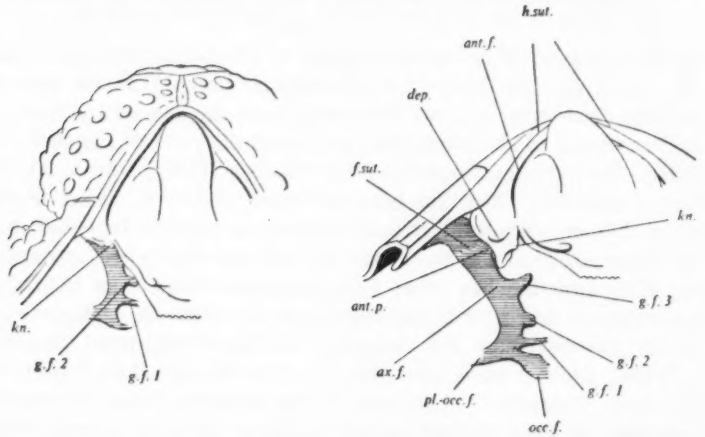
The dorsal surface of the cephalon was first cleaned with a needle to uncover part of the glabella, the anterior part of the right axial furrow and the deep anterior pit opposite the frontal lobe of the glabella, and was then embedded in a block of Picien Wax.[2] In order to do this the cleaned surface was coated with a solution of Picien in carbon tetrachloride and, when the first had hardened and contracted, successive coats were added until the axial furrow and anterior pit had been filled with wax to the level of the cheek and glabella. The specimen was then heated in a sand bath until the wax on its surface was molten. At the same time one end of a stick of Picien was melted, and was then pressed firmly against the dorsal surface of the cephalon until the wax was cold and the two had fused together. With the dorsal

[1] The term "cephalon" strictly includes the hypostome as a ventral member of the cephalic shield; for convenience, however, it is used here in a restricted sense for the dorsal part only of the cephalic shield, i.e. to exclude the hypostome.

[2] This wax is made by Messrs. W. Edwards and Co. (London), Ltd., of Lower Sydenham, London, S.E. 26; it begins to melt at about 80° C., is black, and at room temperature is hard and fairly brittle.

surface thus strengthened it was possible not only to excavate the trilobed central body and one lateral wing of the hypostome and the doublure of the cheek, but also to reveal from below the right axial furrow with the glabellar furrows and the anterior pit. Later the wax was dissolved and there were left the two cleaned surfaces separated in places only by the thickness of the test.

Except for the posterior border, which is broken, the hypostome is complete, although only one side has been entirely excavated. Its main



TEXT-FIGS. 1 (left) and 2 (right).—Outline ventral and oblique postero-ventral views of the hypostome and cephalon of *Encrinurus variolaris* (Brongniart). × 5 approx. SM A 28444.

Explanation.—*ant.f.*, anterior hypostomal furrow; *ant.p.*, anterior pit; *ax.f.*, axial furrow; *dep.*, crescentic depression on hypostomal wing; *f.sut.*, facial suture; *g.f.* 1–3, first to third glabellar furrows; *h.sut.*, hypostomal suture; *kn.*, knob on hypostomal wing; *occ.f.*, occipital furrow; *pl.-occ.f.*, pleuro-occipital furrow.

Note.—The surface granules on the central body and posterior border of the hypostome are omitted. The inner surface of the cephalon is ruled horizontally.

features in ventral view (Text-fig. 1) are essentially as in Fletcher's figure, but the lateral wing is only seen fully in a more oblique view (Text-fig. 2) as it lies in a plane at right angles to that of the rest of the hypostome. It forms an expanded and turned-up [1] continuation of the anterior border of the hypostome, and faces backwards and slightly outwards. The outer surface of the wing is smooth and fairly flat,

[1] In the description " up " and " down " and similar terms are used to denote respectively dorsal and ventral directions relative to the cephalic shield as a whole.

but bears a crescentic depression which is steepest on the side away from the doublure and which passes laterally towards a faint furrow around the outer margin of the wing. Next to this depression on the inner side of the wing there is a knob projecting backwards and slightly inwards. Beyond the depression and the knob, the wing contracts rapidly, but is continued dorsally into a projection which bears on its inner side a flange running forward and inward towards the central axis of the cephalon. The full extent of this flange has not been uncovered. The lateral wing lies very close to the axial furrow, and for some distance in front of the anterior pit the outer margin of the wing is immediately underneath the base of the furrow, although apparently separated from it by a thin layer of matrix. Behind the pit the wing is not so close to the axial furrow although its margin remains approximately parallel. The anterior pit itself is immediately behind the trace of the facial suture across the furrow, and the bottom of the pit, which is not visible from below, must lie just within the edge of the wing above the crescentic depression ; it is unlikely that the pit reaches as far as the knob on the inner side of the wing, although the two are opposite each other. The third glabellar furrow is some distance behind and above the wing, and further back are three other furrows near together. These are interpreted by comparison with similar Dudley specimens as the second and first glabellar furrows and the occipital furrow, the latter forming the truncated posterior end of the cephalon at this point.

Behind the lateral wing the doublure of the cheek is sharply reflexed parallel to the dorsal surface. In front of the wing, however, it is not reflexed but merely slopes in from the margin of the cephalon to the hypostomal suture. The cephalic margin itself rises towards the front—see Salter's figure (1853, pl. iv, fig. 13)—while the suture remains approximately horizontal ; the doublure therefore becomes gradually narrower (tr.) in this direction. At the front end of the hypostome the doublure has practically vanished and the hypostomal suture is effectively marginal to the cephalon.

The cephalon and hypostome of *E. variolaris* seem to have formed together a rigid whole, for it is unlikely that any movement could have taken place during life along the curved hypostomal suture or the facial sutures, although there may have been sufficient elasticity in the integument to allow a very small amount of bending to occur. The possibility of posthumous differential movement of parts of the specimen cannot be overlooked, but there is no evidence that such has taken place ; the hypostomal and facial sutures have not opened, and although there is a small crack across the anterior border of the cephalon, it does not seem to have affected the relative positions of the hypostome and cephalon.

The wing of the hypostome approaches very near to the under side of the axial furrow but has not been proved to articulate with it directly. Indeed it is difficult to understand how a direct internal articulation of these ventral and dorsal parts of the external integument could have taken place in life. There may, however, have been strong muscular or ligamentary connections between the wing and the axial furrow, since the fact that the wing was calcified suggests that its function was to act as a rigid basis for the insertion of muscles directed, presumably, mainly forward and inward.

E. variolaris is quite often found completely enrolled. The edge of the pygidium then fits tightly against the margin of the cephalon, the tips of the posterior thoracic and anterior pygidial pleurae resting in a groove on the margin which reaches forward to the position of the hypostomal wing. The pygidium lies immediately below the hypostome, and it may be that the marked trilobation of the central body of the latter is an accommodation to that of the pygidium. That the shapes of the hypostome and pygidium are closely related is evident also from the other common Dudley *Encrinurus*, *E. punctatus* Auctt. Here the median lobe of the central body of the hypostome reaches forward to a large buttress formed by the rostrum and nearby parts of the glabella at the front of the cephalon. The pygidium in this species is greatly elongated compared with that of *variolaris*, so that in enrolment its posterior doublure reaches beyond the margin of the cephalon to encompass the extended central body and buttress. Even so, specimens of *E. punctatus* are rarely found completely enrolled.

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GEOLOGY DEPARTMENT,
UNIVERSITY COLLEGE,
LONDON.

Cyrtograptids and Retiolitids from County Tipperary

By R. N. Cope

Abstract

Cyrtograptus hamatus, first described from Ireland by Baily in 1862, is now described more fully from fresh material which can be assigned to the zone of *C. lundgreni*. The proximal part of *C. lundgreni* is also described. Three species of Retiolitids occur with the Cyrtograptids, one of which, *Paraplectograptus eiseli* Manck, has not previously been recorded in the British Isles.

Introduction

THE Devils Bit Mountains of northern County Tipperary form the north-eastern part of a large inlier of Silurian rocks. Graptolites were collected by the Irish Geological Survey about 1860 when the area was first mapped and again in 1897 during a revision of the Irish Lower Palaeozoic. During a recent study of the region a large collection of Upper Wenlock and Lower Ludlow graptolites was obtained of which the Cyrtograptids and Retiolitids are especially noteworthy.

Cyrtograptus hamatus (Baily)

Text-fig. 1 A–E

Didymograpsus hamatus, Baily, 1862 a, p. 14, fig. 7.

Graptolithus hamatus, Baily, 1862 b[1], p. 305, pl. iv, fig. 6 A–B.

Cyrtograptus tubuliferous, Perner, 1899, p. 20, text-figs. 25–7, and pl. xvi, figs. 4–6 and 31.

Cyrtograptus hamatus, Elles and Wood, 1916, p. 510, fig. 356, pl. lii, fig. 3.

Cyrtograptus hamatus, Bouček, 1933, p. 46, pl. v, figs. 9–11, text-figs. 8*a–b*.

Cyrtograptus hamatus, Waterlot, 1945, p. 94, pl. xlix, fig. 478.

Lectotype.—G.S.I.[2] 2300h, figured by Baily 1862 a. (Counterpart: G.S.M. 10719, figured by Baily, 1862 b, and by Elles and Wood, 1916). This specimen, showing both the sicula and the branching of the cladium, was chosen because of its relative completeness (Text-fig. 1A). Over sixty fragmentary specimens have been collected and attributed to *C. hamatus*. These show that certain dimensions of the holotype are not representative for the species, probably as a result of slight distortion, together with a non-profile aspect of preservation in parts. The following description is based on all the specimens examined.

[1] Beneath the title of the original paper the date of its reading is misprinted as 1861.

[2] G.S.I. indicates Geological Survey of Ireland Collection: G.S.M., Geological Survey and Museum: and S.M., Sedgwick Museum, Cambridge.

Horizon.—The new material can be assigned to the Upper Wenlock; Zone of *C. lundgreni*.

Localities: Ireland.—County Tipperary, twenty-five localities in the Devils Bit Mountains; e.g. (i) Roadside quarry, 1,150 yards S. by E. of Gortagarry House, and (ii) Stream exposure 1,250 yards S.E. of Gortagarry House. Both localities are about 5½ miles W.N.W. of Templemore. Baily's type locality at Garrangrena, 2¼ miles N.N.W. of Borrisoliegh is no longer accessible. The species is also recorded from Borek, Hinter-Třebaŭ, and Lodenitz in Bohemia (Zone of *Monograptus testis*), and from Morocco.

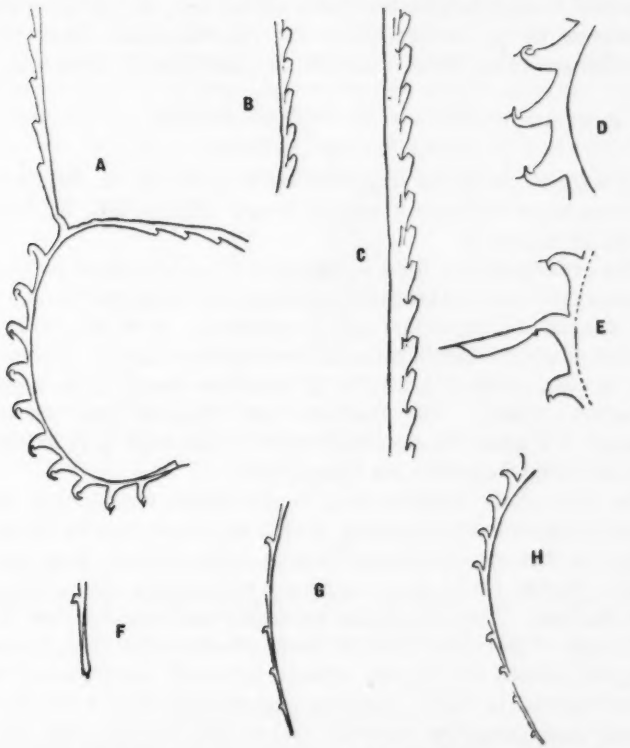
Description.—The rhabdosome consists of a main stipe, curved proximally into a semi-circular arc, and a single cladium. The diameter of the proximal arc varies between 5·5 mm. and 9 mm., averaging 6 mm. in sixteen suitably preserved specimens. The distal main stipe, which commonly has slight ventral curvature, attains at least 4½ cm. in length. The cladium also has ventral, or sometimes dorsal, curvature and attains even greater length, for one specimen was collected showing a cladium 13 cm. long attached to the main stipe.

The sicula is 1·5 mm. long and bears a virgella 0·5 mm. in length. The first theca originates about 0·3 mm. from the base of the sicula. On the proximal arc the thecae are isolate, triangular (with reflexed apertures), and without overlap. Each theca is usually spined and though preservation is poor, it is probable that these represent lateral apertural spines (first two thecae in Fig. 1A). There are nine thecae per centimetre in this region. The width measured aperturally is 0·6 mm. at theca 1 and 0·9 mm. from theca 2 to the cladium, while the width of the proximal part of each theca increases gradually from 0·1 mm. at theca 2 to 0·2 mm. at theca 11. The lectotype shows eleven triangular thecae, the cladium originating on the eleventh.

The main stipe is generally twisted through 180° just distal to the cladium so that the thecae in that region are not seen, but exceptional specimens show one triangular theca after the cladium (Text-fig. 1E). Abruptly following this, the thecae cease to be triangular; whether the apertural region is isolate or there are slight lappets is impossible to determine. The body of the theca shows a distinct sigmoid curvature and there is an overlap of about one-third. There are nine thecae per centimetre, having a width of 0·5 mm. measured aperturally and 0·3 mm. at the base of each theca.

The thecae of the cladium are like those of the distal main stipe (Text-fig. 1B–C). Their spacing changes from nine thecae per cm. proximally to eight distally while the width increases from 0·7 mm. aperturally and 0·4 mm. at the base of the theca, to 0·9 mm. and 0·5 mm. respectively distally. The lectotype cladium does not show these characters owing to its aspect of preservation.

Affinities.—Although some of the proximal thecae of *C. lundgreni* closely resemble those of *C. hamatus*, the much greater curvature of the latter form is distinctive. Distal stipe and cladium thecae are



TEXT-FIG. 1.—A, *Cyrtograptus hamatus* (Baily): Holotype. G.S.I. 2300h. × 4. B, *C. hamatus*: proximal cladium thecae (8th to 12th thecae). S.M. A 24,404. × 4. C, *C. hamatus*: distal cladium thecae (detached fragment). S.M. A 24,378. × 4. D, *C. hamatus*: proximal main stipe thecae showing spines. G.S.I. 2286h. × 8. E, *C. hamatus*: the origin of the cladium. S.M. A 24,403. × 8. F, *C. lundgreni* Tullberg: the sicula and theca, 1. S.M. A 24,405. × 9. G, *C. lundgreni*: same specimen as F, showing early thecae. × 4. H, *C. lundgreni*: proximal thecae showing change of shape . S.M. A 24,406. × 4.

similar to those of *C. carruthersi*, but the latter is slightly wider and has more widely spaced thecae.

Associates.—*C. lundgreni*, *M. flemingii*, *M. dubius*, *M. vomerinus*, *P. eiseli*, and *R. spinosus*.

Collections.—Sedgwick Museum, Cambridge; Liverpool University, Department of Geology; British Museum of Natural History.

Remarks.—Distal stipe or cladium fragments of *C. hamatus* were

identified as *M. nilssoni* following the 1860 survey of County Tipperary and it is possible that in other places they have been mistaken for *C. carruthersi*. Such misidentification may account for the lack of records of *C. hamatus* elsewhere in the British Isles, and for the recorded occurrence of *C. carruthersi* in the two separated zones of *M. riccartonensis* (from which it was first described) and *C. lundgreni*.

Cyrtograptus lundgreni Tullberg

Text-fig. 1 F–H

Cyrtograptus lundgreni Tullberg, 1883, p. 36, pl. iii, figs. 8–11.

Cyrtograptus lundgreni Elles and Wood, 1916, p. 507, fig. 353*a–b*, pl. lii, fig. 1*a–d*.

This zone-fossil has been collected at fifteen localities in County Tipperary and conforms to previous description (Elles and Wood, 1916). The material is fragmentary and no specimens show more than one cladium in place. Identification of incomplete examples was possible only by comparison of a number of specimens covering the range of characters present. The fragments are relatively well preserved, however, and since the proximal region of the stipe is little known, some proximal fragments are figured here.

The stipe of *C. lundgreni* has, in the sicular region, only slight dorsal curvature. This increases distally to a maximum at the origin of the first cladium. The sicula (Text-fig. 1F) is 0·9 mm. long and has a short virgella while theca 1 appears to originate about 0·4 mm. from the base. The early thecae are isolate and hooked, there being about eight of this type. There is then a change within three thecae to triangular shaped thecae with reflexed apertures, accompanied by a marked increase in width. The apertural width of theca 1 is 0·25 mm. and the width across the proximal part of theca 2 is 0·1 mm. Corresponding maximum measurements of 1·0 mm. and 0·4 mm. are seen at about theca 15, most of this increase taking place from theca 8 to theca 11. The spacing of the thecae also changes in this region, there being about eight and a half thecae per centimetre in the proximal part increasing to ten thecae per cm. after theca 10.

Paraplectograptus eiseli (Manck)

Text-fig. 2A–B

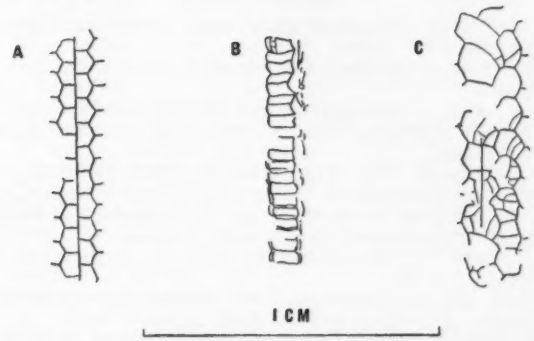
Retiolites eiseli Manck, 1915–17, p. 338, figs. 1–5.

Paraplectograptus eiseli Bouček and Münch, 1952, p. 136, pl. i, fig. 8.

Three localities have yielded numerous specimens of a Retiolitid which may confidently be assigned to the above species. This species does not appear to have been recorded previously in the British Isles.

The profile view (Text-fig. 2A) is the most distinctive aspect of preservation, showing the pentagonal meshes of the clathria, the virgula or median strand in the wall of the stipe and the stout apertural spines. No reticula is seen. Proximally there are fourteen thecae per cm., decreasing to twelve distally. The width excluding spines increases from 0·9 mm. to 1·4 mm. In scalariform view (Text-fig. 2B) the proximal width is 0·6 mm., increasing to 1·0 mm. distally while a maximum width of 1·8 mm. may be attained in intermediate aspects.

The best locality is the large roadside quarry 1¾ miles N.N.E. of Holyford. Here and elsewhere in the region the horizon is the *C. lundgreni* zone.



TEXT-FIG. 2.—A, *Paraplectograptus eiseli* (Manck): profile view. S.M. A 24,381. × 4. B, *P. eiseli*: scalariform view. S.M. A 24,381. × 4. C, *Plectograptus macilentus* (Törnquist): profile view. S.M. A 24,382. × 4.

Retiolites spinosus Wood

Retiolites spinosus Wood, 1900, p. 485, text-fig. 26*a–b*, pl. xxv, fig. 29*a*, *b*.

This species is rare in the Devils Bit Mountains and only two specimens have been found at a single locality in the *C. lundgreni* zone.

Plectograptus cf. *macilentus* (Törniquist)

Text-fig. 2C

Retiolites macilentus, Törnquist, 1887, p. 491, fig. 3.

Plectograptus macilentus Moberg and Törnquist, 1909, p. 13, pl. i, figs. 1–12.

Plectograptus macilentus Bouček and Münch, 1952, p. 120, pl. i, figs. 1–4.

One specimen was found which Dr. I. Strahan has identified as the above species from the figures of Moberg and Törnquist. It measures 9 mm. long and has the equivalent of ten thecae per cm. The width increases from 1·5 mm. at theca 1 to 2·2 mm. at theca 8. The clathria

is well developed and the virgula or median strand is not incorporated in the stipe wall. The reticula is coarse and patchily preserved.

The horizon of the specimen is the Lower Ludlow zone of *Monograptus tumescens*, and therefore agrees with Törnquist's original specimens which were from the Lower Ludlow. The locality is the roadside quarry, one mile due north of Kennedy's bridge and six miles north-west of Templemore.

I wish to thank Dr. I. Strahan for assistance with identifications and Dr. J. C. Harper for his frequent advice. The work was carried out during the tenure of a D.S.I.R. award.

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DEPARTMENT OF GEOLOGY,
UNIVERSITY OF LIVERPOOL.

CORRESPONDENCE

RULES OF NOMENCLATURE

SIR,—W. J. Arkell (*Geol. Mag.*, 1954, 91, p. 174: *Jour. Paleont.*, 1954, 28, no. 2, p. 218) has recently attacked clause 54 (1) (*a*) of the " Copenhagen Decisions on Zoological Nomenclature ", which provides that a change in the name of a type genus because of synonymy, whether objective or subjective, will not necessitate a change in any family-group name founded upon it. The purpose of this decision was to provide greater stability and continuity to names of the family group, especialiy those of families and superfamilies that are of wide and general usefulness and importance. It is accordingly surprising to find such a worthwhile provision so vehemently opposed. If, indeed, the decision would produce " unhappy effects " and " completely unfamiliar monstrosities ", and if it would result in a " discreditable hunt . . . to be first to unearth these corpses [junior synonyms] for revival ", I am sure that those of us who warmly supported it at Copenhagen would join Dr. Arkell in denouncing it. But it seems clear that Dr. Arkell has misread the decision and has misjudged its effects. It is to be hoped that his forceful language has not prejudiced the case.

(1) The Copenhagen decision actually reads " where the name of the type genus . . . has to be changed because it is found to be . . . [a junior synonym] ", and not, as Dr. Arkell gives it, where it " *has been* changed because it is . . .". His fears of the ghosts of long-buried junior synonyms are understandable if one begins with his verb tenses, but *not* with those adopted at the Congress. Clause 54 (1) (*a*) as it stands is specifically designed to avoid changes *in the future*. A procedure that can be applied to the past is given in clause 45, which Dr. Arkell does not mention.

(2) Under the old Code, when the type genus was found to be a junior synonym, *both* generic and group names had to be changed, including those of tribe, subfamily, family, and superfamily, if all were involved. Changes in at least the higher group names usually had wide repercussions in unfamiliarity and inconvenience in collateral fields and in teaching. Under the Copenhagen plan, when such synonymy occurs, the rule will not require any changes of family-group names. This will give consequent advantages in stability, continuity, and familiarity. Under Dr. Arkell's proposal, however, we would revert to the old Code, under which changes would be required in those cases. We would be forced in the future to change family-group names to those new and hence " completely unfamiliar " group names which he himself dislikes. Furthermore, in cases of subjective synonymy, we might have to change names frequently, in keeping pace with changing subjective views of authors.

(3) Even if Dr. Arkell's interpretation were correct, authors who wished to avoid exhuming old group names based on long-buried junior synonyms would have only to maintain current usage while following the procedure provided in clause 45. Surely it is a mistake to lift clause 54 (1) (*a*) out of the plan and criticize it without relation to other provisions, especially those of clauses 45 and 54 (2).

(4) It should be noted that the views of Dr. Arkell, and also those of Dr. R. C. Moore, the leader of the Treatise of Paleontology currently in progress, were published in the *Bulletin of Zoological Nomenclature* prior to the Copenhagen meeting, along with many other expressions of opinion and arguments pro and con. All of these were before the Copenhagen Colloquium, which considered the problem in detail and recommended the plan on family-group names to the Commission and thence to the Section on Nomenclature and the Congress. Paleontologists were represented at all stages, and the views of Arkell, Moore, and others were known and their viewpoints argued. There was, of course, difference of opinion on this point, as there was on many points. But the decision in clause 54 (1) (*a*) was arrived at by the substantial majority of 20 to 8 after lengthy discussion of the advantages and disadvantages, on the first and least hurried day of the Colloquium, and

under the best circumstances in which nomenclatural decisions have ever been taken.

In England, more than twenty-five years ago, the British National Committee on Entomological Nomenclature formally proposed that a family name was not to be changed unless it or the name of its type genus was found to be a homonym. That Committee included such well known zoologists as Karl Jordan, S. A. Neave, and G. A. K. Marshall. Support for this solution of the problem has been growing in the last decade, and those who now wish to repeal it should realize the large amount of opinion on the other side. In the *Bulletin of Zoological Nomenclature* for July, 1953 (vol. 8, nos. 6/9), in which were published the views of Arkell and Moore, there are a number of statements in favour of *not* changing family names in cases of generic synonymy. The proposition of not changing was supported by several groups which gave special consideration to the major problems to come before the Copenhagen Congress—namely, the Nomenclature Committee of the Society of Systematic Zoology (W. I. Follett, Chairman: six out of eight members clearly expressing support), the American Committee on Entomological Nomenclature (C. D. Michener, Chairman), the Committee on Nomenclature of the American Museum of Natural History (John T. Zimmer, Chairman), and the Nomenclature Discussion Group of Washington, D.C. (R. E. Blackwelder, Secretary: approved by nearly two to one majority). Paleontologists are represented in three of those four groups. In a specialized field, the insect order Diptera, a questionnaire sent to dipterists all over the world in 1952 showed 69 per cent of 166 votes in favour of the solution as later adopted at Copenhagen. It thus appears that the Copenhagen vote was a fair sample of the views of zoologists.

(5) In the long view, if a great proportion of animal species remains to be discovered and named (estimates for neozoology alone range from 50 to 90 per cent), the number of generic and group names yet to be proposed and shuffled about with successive classifications and reclassifications will be considerable. Any rule that will render some name changing unnecessary for the future, as does clause 54 (1) (*a*), will be a great boon and should not be discarded.

CURTIS W. SABROSKY.

ENTOMOLOGY RESEARCH BRANCH, AGRICULTURE RESEARCH SERVICE,
UNITED STATES DEPARTMENT OF AGRICULTURE.
June, 1954.

THE CARIBBEAN "OLIGOCENE"

SIR,—Dr. Stainforth's comments on my recent paper on the Miocene–Oligocene boundary, especially in so far as they affect the Caribbean region (*Geol. Mag.*, xci, No. 2, pp. 175–6, 1954), suggest that he has missed the object of the paper. I am familiar with the selected references cited by Mr. Stainforth, as well as many more concerning the Central American region and many others dealing with marine Miocene and Oligocene faunas in other parts of the world: only a few selected recent papers having a fundamental bearing on the subject were quoted in my original paper probably for the same reason as Dr. Stainforth—because a comprehensive list would have been impracticable as it would fill a whole issue of this periodical.

A study of the more recent literature, referred to in part before, indicates that there is a growing school of workers who recognize that the upper part of the so-called "Oligocene" in the Caribbean region is probably of Lower Miocene age: this is the view that I fully endorse as a result of researches carried out in many parts of the world over a period of nearly thirty years. It is evident that two important and world-wide palaeontological changes are involved, one between the Eocene and the Oligocene, the other between the Oligocene and the Miocene, the latter occurring well below the so-called "Miocene/Oligocene" boundary as interpreted until recent years in the Caribbean region. Consequently, I am firmly convinced that the faunal

succession in the latter region is not out of phase with that in all other parts of the world, and that beds with *Miogypsina*, *Orbulina*, *Candorbulina* (for example) and their associated faunas, as now known, are all unquestionably of Miocene age. The evolutionary succession of *Miogypsina sensu stricto* (see Drooger) lies entirely within the Miocene.

Finally, I would point out that Dr. Stainforth, throughout his writing, is using the terms "Oligocene", "Miocene", and "Aquitanian"—all the stages being defined in Europe—as if they were unquestionably used correctly in the Caribbean region. This I maintain is not the case. It is imperative that subscribers to this view should purge their minds of all preconceived ideas and review and assess the palaeontological evidence from the Caribbean region again and compare it anew with modern and up-to-date evidence from other parts of the world. My conclusions have been based on such studies. Not all those who study the Caribbean Tertiaries appear to have carried out such investigations and this is hindering the promotion of a sound and orderly understanding of the evolution of Tertiary faunas and of their world-wide correlation.

F. E. EAMES.

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21st May, 1954.

REVIEWS

Mountain Building[1]: An Essay Review

By W. B. HARLAND

In the first part of his recent book Van Bemmelen summarizes his undation theory developed over many years and connected with the ideas of Haarmann, Stille, Cloos, Bailey Willis, and many others in different ways. This hypothesis is generally known to the English reading world through his paper to the International Geological Congress in 1933.

In the second and larger part of the book he applies this to, and endeavours to support it from, a study of the orogenic evolution of the earth's crust in Indonesia. In so doing he summarizes parts of his massive *Geology of Indonesia* (1949) itself a synthesis and interpretation of a century of geological investigation by many Dutch geologists.

The second part with its chapters on stratigraphy, volcanism, tectonics, and geophysics, concludes with a summary of the geological evolution of Indonesia. All these chapters are elementary in the sense that much is devoted to definition and introduction, while the local detail is brief and not supported by references. From this there is little chance of assessing critically Van Bemmelen's hypothesis in terms of the evidence presented; on the contrary the regional description is presented as an illustration of what is implied in the full development of his hypothesis. In so far as the author has already made such a full and well documented account available in his *Geology of Indonesia*, this is not a serious criticism, and the book is thereby made conveniently brief and readable. It could have been further shortened by omitting some of the introduction to stratigraphy which ranges from an explanation of unconformity to several detailed schemes for dividing and correlating the Tertiary without any attempt at an assessment of their application.

However, this book will be of interest as a recent exposition and application of the undation hypothesis to the problem of mountain building.

[1] *Mountain Building*, by R. W. Van Bemmelen, pp. xii + 177, with 51 figs. Martinus Nijhoff, The Hague, 1954.

"*The Undation Theory.*"

The detailed structures of mountain systems are interpreted as due to gravity sliding from uplifted areas (secondary tectogenesis). The necessary vertical movements (primary tectogenesis) take place as a result of the migration of material upwards in localized areas so as to form a blister (asthenolith). This less dense material (neo-sial) is separated from a global layer of basaltic composition (salsima, sialma, etc.) which at the same time generates a complementary root of ultrabasic composition (neo-sima). The separation of the salsima into more acid and basic layers above and below (hypo-differentiation) is followed by an inflow of more salsima, causing a thickening of the crust (undation) which may be of any extent. Uplifts of continental scale (geo-undations) are not specifically treated in this book, which confines its attention to the structures found in the island arcs of Indonesia and accounts for them by smaller developments (meso-undations). The Mohorovičić discontinuity is thought to separate all these materials and events from a primary "sima" beneath conceived as a peridotite layer.

Van Bemmelen regards the Earth primarily as a geochemical, rather than as a rotational, thermal, or radioactive engine. However, the trigger which releases this geochemical energy and localizes the undation is cooling and the ensuing "exothermic chain reactions" cause differentiation accompanied by a steady upward migration of volatiles. Chemical changes will result in materials of differing density and mobility, and the net result at the surface is the vertical movement (primary tectogenesis).

"*Bicausal-fixistic hypothesis.*"

It is a common debating technique not unknown in scientific writing to support a view by contrasting it with a series of improbable or extreme alternatives. The "bicausalistic" quality of the undation theory refers to the two stages of primary and secondary tectogenesis. In "unicausalistic" (one would prefer mono-) views, tangential compression is conceived as the whole process from bringing the geosyncline into being to the final folding and thrusting of its contents.

Ven Bemmelen makes a second division between two groups of theories or ideologies, the "fixistic" and "mobilistic", epitomized in the views of Stille and Argand respectively. A contrast between "orthodoxy" and "drift" is implied, but the real issue is between a concept of considerable radial movements giving rise to secondary tangential movements, and great horizontal movements from which vertical adjustments derive. "Fixism" leaves the Earth's surface relatively undistorted in plan through geological time, while "mobilism" does not. It is unfortunate that this quite useful contrast is elevated to a fundamental dichotomy severely limited at the outset by a complete rejection of any contraction hypothesis. Few hypotheses developed in any detail could lie for long on one or other branch. The logical dilemma is aggravated by linking the two factors, and so dividing the world into opposing ideologies: the "unicausalistic-mobilistic" and the "bicausalistic-fixistic".

If we follow R. C. Moore's suggestion in his Introduction to the book, as Van Bemmelen is reluctantly prepared to do, and call these two groups of hypotheses simply lateral compression hypotheses and plutonic hypotheses, an ugly terminology would be avoided, but many implications would be lost, and much of the book would have to be rewritten. As no present hypothesis approaches finality, and no final theory will avoid incorporating several mechanisms, it is proposed to examine in more detail the two principal features of the undation hypothesis, interpreted as tectonics by gravity and tectonics by granite.

Gravity tectonics.

Gravity sliding has been a serious factor in tectonic hypothesis for nearly a hundred years, since James Hall postulated the final collapse and folding of the thick deposits in the Appalachians. As a secondary mechanism it has

been entertained by many since Schardt's interpretation of the Pre-Alps. Van Bemmelen argues reasonably enough that folds are visible, but the absence or attenuation of rock is not so evident ; therefore compression may have been systematically over-estimated just because extension has been under-estimated. It is then stated that observed compression is too great to be accounted for by thermal contraction alone, and some other mechanism must be sought. Jeffreys has been fully aware of this difficulty, and when hard pressed to account for all the apparent crustal shortening in any great circle, he used precisely this argument in defence. Since then Jeffreys (in the second edition of *The Earth*) has been able to modify his assumptions, and so accommodate still more compression as crustal shortening. Without being hampered by the same geophysical assumptions, G. M. Lees (in his recent presidential address) claims a far greater crustal compression on purely geological evidence. Ideas based on the concept of crustal shortening not necessarily due simply to thermal contraction, have by no means been exhausted (as Van Bemmelen thinks), nor are they necessarily excluded as a primary process, even if much of the secondary tectogenesis of Van Bemmelen be accepted. Compensation of compression in one place by extension in another may be envisaged on an orogenic scale as gravity sliding or on a continental scale as the essential feature of continental drift.

In the second part of the book (Chapter IV) there is a more detailed discussion of gravitational tectogenesis with specific examples from Indonesia. Three depths or scales (epidermal, dermal, and bathydermal) are described. Several varieties of the superficial slides are described, including land slides, collapse of volcanoes on foundations of unconsolidated sediments, squeezing out of plastic strata from beneath later but more rigid deposits, and collapse-folding into sedimentary basins. It may be presumed that all these cases of superficial structures are well attested, and they have to-day a familiar aspect. The structures attributed to collapse and sliding of sheets at greater depth are naturally more difficult to demonstrate.

There has been a growing sympathy with gravity tectonics or " écoulement par gravité " in several applications. Harrison and Falcon's gravity collapse structures, Jones' slumping, Barrington Browne's gravitational sliding, Migliorini's Argille Scagliose, to mention only a few instances, have produced a climate of opinion in which orogenic structures as a whole may be sympathetically viewed as due to gravity sliding. A mechanical obstacle to very considerable thrusting (because of the strength of rock in relation to the great size of many nappes) has long been recognized, as also to gravity sliding over great distances (because of the inability of the crust to support a mass of the height necessary for a reasonable angle of slope). Some have rejected one or other of what seemed to be two alternatives for the explanation of great tectonic slices. A fuller mechanical appreciation shows that on the alpine scale of deformation it is impossible to isolate simple compression thrusting or simple gravity sliding except at the surface. Deformation at depth, and that is often what we now see exposed, may be imagined by analogy with scale models as a form of turbulent flow. Various mechanisms may produce such structures ; for example, drag due to deeper circulation (convection or asthenolithic), compression (high level, low level, local or general), uplift and collapse (magmatic or compression). The difficulty of accepting very large scale thrusting is not an argument for or against any of these.

Granite Tectonics.

The essence of the undation theory however is the primary tectogenesis and this is a plutonic concept whose evidence is sought not only in the general sequence of tectonic events, but also more directly in the date of petrology and geophysics.

As in nearly all geotectonic hypothesis cooling is thought to be the primary cause of the disturbances which are therefore localized in the first place by the pattern of the cooling. Differentiation, and the upward migration of

more volatile constituents (with attendant migmatization) produces a mobile nascent asthenolith of high volatile content and low density and a heat content carried upwards from the exothermic process of differentiation. It is presumed that there is an equivalent ultrabasic product separating beneath. The whole is an undation. The tendency to maintain hydrostatic (and isostatic) equilibrium leads to a replenishment of basic salsima in the centre and a spreading of the products of differentiation from the central areas. In this process of spreading, the differing mobility in these various layers is thought to produce transient gravity anomalies and the various movements characteristic of the island arc system.

More layers beneath the Earth's crust are therefore assumed than in some hypotheses from which follow more possibilities of variation in space and time. Such an assumption, for whatever reason it may be made, automatically carries with it far greater possibilities of vertical movements consistent with isostatic equilibrium. If the idea of some plastic flow at various levels of different density be entertained, mountains and even continents may be uplifted or founder in imagination without violence to isostatic principles. Such ideas are at the root of one school of hypotheses of orogenesis, but may be held in reserve by many not wedded to a particular explanation, and who do not wish to be limited by geophysical dogma in their geological deductions.

These possibilities at depth, however, have little evidence at the surface to help distinguish between them. The effects of the uppermost of these deep generated layers—the asthenolith—is claimed to have many visible effects in a whole train of tectonic and vulcanological events. The Atlantic suite, characterized by its negative correlation with tectonic activity is claimed as a direct sample of the basaltic layer (salsima) where differentiation has not yet begun. The Pacific or orogenic suite is the product of the neo-sial or asthenolith layer and the Mediterranean suite is considered a pathological variety of this due to the assimilation of limestones. Finally the basic and ultra-basic rocks in orogenic belts are not directly related to the deep layers of the earth crust (as supposed in Hess's concept of the tectogene), but are manifestations of the presumed basic fronts associated with the migmatization of the asthenolith. The whole geosynclinal ophiolitic facies is so regarded. Finally the post orogenic granites float up through the overlying structures, giving a sample of neo-sial at the surface. Another and later post orogenic manifestation of these deep events may be the eruption of plateau basalts from a magma layer poor in gases at the base of the sialic crust.

Here is food enough for thought and for argument too. It is unlikely that this entire model will become emplaced in geological thought so simply, but parts of this mechanism may well serve a useful purpose, and indeed have already done so. Granite is presumably the crystalline product of the upper part of an undation. Undations are said to be measured in tens, hundreds, or thousands of kilometres ; so we have a granitic layer, actual or potential, between the surface and basaltic layers which may be thick and mobile beneath mountains, thinner elsewhere, and absent in places.

In *Mountain Building* Van Bemmelen does not tell us about these larger undations (geo-undations), we are restricted to a smaller geanticlinal scale (meso-undations) within Indonesia. Given a geosyncline, a detailed sequence of events is postulated within it to account for the history of mountain building in the East Indies. It is interesting to note that as in Vening Meinesz's convection theory different scales of process are envisaged. Global circulation might produce continents which in turn would produce a reversal of the circulation on a smaller scale, resulting in orogenic belts of compression. These finally would again reverse the circulation by accumulation of radioactive heat at their roots and produce the various gravitational, seismological, vulcanological, and tectonic features of the East Indian island arcs. Vening Meinesz only claims direct evidence for this third order convection which could derive from but not produce fold mountains. In the course of time the motive power for major orogenesis would appear to be dissipated and something of the same sequence of major, minor, and

minimum tectonic events would seem to be implied in the undation concept. Certainly the most direct evidence, much the same as that used by Meinesz, applies to a mountain system which is now hardly in the same class as some of the other fold systems of the world.

A comparative study of tectonics from the literature reveals many contrasts between mountain chains and even between different sectors of the same chain. While this is partly due to the personal views of the authors, there are real differences too. Some tectonic belts appear to show marked compression with or without igneous activity, in others vertical movements, often with igneous activity, appear to be dominant. It is suggested here that while some secondary aspects of the undation hypothesis may be of general application, plutonic uplift may only be primary in certain belts if at all, and secondary in many others. Even if the island arcs of Indonesia be explained, as Van Bemmelen does, the application may not apply, for instance, to the Betic cordillera which in his youth, as he now thinks mistakenly, he interpreted as due to tangential compression.

In conclusion, if we attempt to explain the variety of tectonic structure, we shall do well to avoid at this stage accepting any such total theory, and rather apply the method of multiple hypotheses. By breaking down each complex concept into its elements and holding these separately and loosely, they will be ready to be used in a variety of mechanisms ; a variety which diminishes as new evidence rules out certain possibilities. If not wholly acceptable, the undation hypothesis has given Van Bemmelen the energy to achieve a massive contribution to descriptive geology and provide us with a summary of suggestive views on tectonics by gravity and by granite.

THE COALFIELDS OF GREAT BRITAIN. Edited by Sir ARTHUR TRUEMAN. xi + 396 pp., with numerous figures. Edward Arnold (Publishers), Ltd. London, 1954. Price 63*s*.

To quote the Preface : " When this work was first planned it was the hope of the editor to write himself the greatest number of the chapters," but owing to the demands of public service and to ill health, and to " the continued growth of detail concerning each coalfield, he has found it necessary to call on an increased number of collaborators ". There are nine of them, each possessing special knowledge of the field or fields he has described. All have admirably succeeded in following, " as far as the area permitted, the plan of headings, necessary to keep the greatest uniformity in treatment."

Again to quote from the Preface : " The present work is intended to supply mining engineers and students, particularly of mining and geology, with a balanced account of the geology of coal and of the structures and resources of the coalfields of Great Britain."

The first five chapters, dealing with general principles, have been written by Sir Arthur himself—" Coal as a Rock ", " The Rocks of the Coal Measures ", " Geological Structures ", " Fossils of the Coal Measures and their Use ", " The Origin of the British Coalfields ". These are designed primarily with a view to their usefulness to mining engineers, but being both concise and up-to-date, they will appeal strongly to geologists—and the last chapter is a really masterly statement of the present knowledge of how the Coal Measures were related to the then-existing geography, and how the tool of palaeontology, in particular the use of the non-marine lamellibranchs which we owe largely to Sir Arthur and his disciples, and the use of the marine bands and floral zones has enabled the sequences in separate coalfields to be correlated and interpreted, and how it has given greater precision to our knowledge of the structures on which the winning of coal so largely depends.

These early chapters naturally stress the value of the fossil evidence, but they also focus attention on a number of other features, once disputed but now generally accepted almost as commonplace : such are the validity of the *in situ* theory of coal formation and the paralic delta origin of most of the

British coal-bearing rocks; the original continuity of coal measure formation over wide areas rather than local isolation in a number of basins (there are exceptions of course); and the value of the rhythmic pattern of sedimentation (*cyclothems*) in the correlation and identification of seams. The recognition of the validity of these hypothetical conceptions has come about during the last thirty or forty years through the application of standard methods of stratigraphical and petrological research to what had previously proved to be very intractable material. The editor himself and the other authors have all made original contributions to our knowledge along these lines; it is good to have such an able exposition of the results as we find condensed in this highly readable introduction.

These chapters also serve as a vindication of the view that the universities should teach "pure" not "applied" geology to mining and engineering students, since it is an appreciation of the basic principles of the subject which will be of value to them in after-years, and they can be trusted to apply them to their own particular fields of work; without them, they cannot even "understand the language".

If one be permitted to venture a criticism, it is that hardly enough attention is drawn to the unproductive cover which has so often to be penetrated before the coals can be reached, and which may place unwished-for limitations on their exploitation. It seems also a pity that the account of the petrology and structure of coal seams is so restricted, on the supposition that the reader will have access to Raistrick and Marshall's *The Nature and Origin of Coal and Coal Seams*.

For illustrations to Chapters i–v, Sir Arthur has made use of a number that accompanied his Presidential Addresses to the Geological Society, but Chapter iv (referring to the fossils) has been furnished with a set of new figures of typical Coal Measure forms drawn specially for the book by Dr. R. M. C. Eagar, himself a palaeontologist who has made important contributions to their study.

Turning now to the eleven chapters, each descriptive of a single coalfield or of a related group of fields, and each written by a "collaborator", one cannot attempt to draw comparisons between them, but only to review the general character of this section of the book. It is at once clear that each of the nine authors has made a loyal attempt to treat his subject on a common plan agreed to by all and probably largely designed by Sir Arthur. This gives a sense of uniformity of treatment which is gratifying in view of the great differences in stratigraphy and structure displayed by British coalfields—the northern ones drawing their wealth from almost the whole gamut of the Carboniferous in contrast to the limited range of the productive rocks in, say, the Forest of Dean: some fields being "exposed", others largely or completely concealed: some slashed to pieces by giant faults, others almost undisturbed. While the method adopted inevitably tends to perpetuate the usual treatment of the coalfields as a number of isolated units, the adherence to a common plan of exposition which has taken full advantage of the results of modern zoning, has resulted in this sense of isolation being minimized by reason of the correlations implied by the zonal treatment. The careful reader of Chapters IV and V on the "Fossils" and on "The Origin of the British Coalfields" will be still further assisted in any attempt he may make to weld the isolated descriptions into a general picture.

The following is an alphabetical list of the distinguished contributors and of the coalfields that they have described in these eleven chapters. F. W. Cope, North Staffordshire: Wilfrid N. Edwards, Yorkshire–Nottinghamshire: W. Hopkins, Northumberland–Durham: Murray Macgregor, Scotland: G. H. Mitchell, South Midlands: L. R. Moore (1) South Wales, and (2) Forest of Dean and Somerset–Gloucestershire: C. J. Stubblefield, Kent and possible concealed fields of S. England: F. M. Trotter (1) Lancashire, and (2) Cumberland: Alan Wood, North Wales. It will be at once evident that Sir Arthur has obtained the service of leading experts, and that each chapter carries the hall-mark of authority. The reader of these eleven chapters will, no doubt, sense subtle differences in the manners of presentation, differences

that are related both to the authorship of the chapter and to the problems with which each writer has been faced; but in each article there is brought together a great deal of up-to-date information that is hard to come by elsewhere. True, most of it has been published, but in a very scattered manner or in technical papers that assume more knowledge than the average reader possesses. Here it is all set out in an orderly manner and presented in such a way that it is not hard to draw comparisons between the different coalfields. There is also concise information about the structures and the local nature of the coals, the reserves, and other economic matters.

The exigencies of space have led to an awkward degree of compression in the descriptions of the larger and more complicated fields. This is, however, only one example of what must be regarded as a defect if the book is intended primarily for students, namely that while the general descriptions in each chapter are admirable, the details of the local distribution, development, and variation of composition, etc., of the coals and coal measures and the local complexities of structure make very difficult reading without more detailed maps and sections than those provided (which, by the way, are quite adequate for their intended purposes). Such local features are so important in mining practice that each specialist has felt obliged to introduce more of them than necessary for the audience which is postulated in the Preface. On the other hand, the reviewer was in need of information on certain points of detail in more than one coalfield, and in each case found an answer to his query.

With regard to the production of the book, there is a commendably high quality in the draughtsmanship of the illustrations and in their legibility; and printer's errors are rare. Wrong compass directions occur on pp. 154, 163, 205; and surely *fore-deep*, not *forefront* was intended on p. 92?

Summing up, it is clear that we have in this book a first-class work of reference characterized by its comprehensiveness, its authority, its clarity of plan and expression, and above all by a most exceptional feature in a text-book—its remarkable up-to-dateness. This makes it indispensable to-day to all students of coalfield geology, and will ensure its usefulness for many years to come. Alas, its price (three guineas) is also up-to-date! Nevertheless the reviewer feels that all geologists who read this book will want to say "Thank you, Sir Arthur Trueman! Of all recent Coal Measure research, your's on the non-marine lamellibranchs has been the most fruitful, providing us, as it has, with the key to the problem of the regional correlation of the local developments. Congratulations, Sir Arthur! on the symposium which will long remain the standard textbook on the British Coal Measures, and, what is perhaps more important, will be an enduring witness to the value of *pure* geological research to the economy of our country".

L. J. W.

GEOLOGY AND SCENERY IN BRITAIN. By T. G. MILLER. pp. 224, with 38 text-figures and 47 half-tone illustrations. B. T. Batsford, Ltd. 18*s*. net.

This is in parts an excellent book, but it does not justify the claim on the jacket that "it is immediately comprehensible to the non-expert reader". The author has fallen into the error, by no means uncommon nowadays, of supposing that writing in what may be called a literary instead of a scientific style necessarily makes a scientific subject more comprehensible to the layman. He has, however, produced an account of the relation between geology and scenery in England and Wales (not Britain as stated in the title) that should appeal to those with some knowledge of the subject by reason of the interesting and lucid manner in which many of its aspects are presented.

Some quite original analogies have been introduced to illustrate geological processes and phenomena. Most of them are successful, e.g. the illustration of some of the effects of Tertiary Alpine folding by comparison with the compression of loosely interlocking paving stones resting on a not quite rigid floor and covered with a thick blanket. On the other hand, the comparison between the South Wales Coalfield and "a pile of oval meat-dishes stacked on a southward sloping surface and pressed into this surface so as to

rest on a dimple in the basement " may be understood by geologists familiar with the coalfield structure but is less helpful to the non-geological reader than a simple account of the sedimentation, folding, and denudation of the strata concerned.

For convenience of description the country is divided into eight regions, and whilst their boundaries are well chosen the choice of the name " Young Wales " for a region including the Mendips is not a happy one, especially since it leads to a caption describing Cheddar Gorge as in the south-eastern corner of Young Wales.

An attempt to cover too large a field in the space available to the author has resulted in statements that are misleading because only the informed reader would know wherein they needed qualification. For example, to say that " no iron ore is now worked in South Wales " is quite wrong, though it is true that the Coal Measures ironstones are no longer worked.

To summarize the geological history of Carboniferous times in about thirty words—On the floor of this sea limey mud gathered and became the Carboniferous Limestone: the sea retreated, river deltas spread and advanced, forests occupied the flats, and the Coal Measures were made—is a masterpiece of concise writing, but does it mean much to the " non-expert reader " ? There are passages that could have been omitted from the book without loss in order that others like this could have been expanded. One such relates to the Pembrokeshire origin of the blue stones of Stonehenge: the author says that " the official view attaches some special significance to the stones of this particular area ", but without indicating what the official view is, why it is " official ", or the evidence upon which it is based, he offers an explanation of his own, which, although no doubt intended to be facetious, is out of place in a work of this kind.

The half-tone illustrations are excellent, although it is difficult to see why about one-third of them should relate to foreign countries or parts of Britain not dealt with in the text. Carn Llidi in Pembrokeshire is wrongly described as part of the pre-Cambrian foundation. The text-figures reach an unusually high standard both in design and execution : except in a few instances they admirably demonstrate the point they are intended to make, and will be welcomed by student and layman alike. F. J. N.

MINERALS FOR THE CHEMICAL AND ALLIED INDUSTRIES. By SYDNEY J. JOHNSTONE. 692 pp., with 174 tables. Chapman and Hall, London, 1954. Price 75*s*.

At heart all geologists are prospectors, and to the needs of those geologists who direct or follow the practice of prospecting for economic minerals this encyclopaedic store of statistical and chemical information is well suited. It is a collection of discrete essays, by a chemist who has recognized that without continued investigation and discovery of new locations of minerals by geologists, the maintenance of supplies of raw materials for the industrial chemist cannot be assured.

Each of the seventy essays tells shortly what is done with mined minerals or rocks (other than coal and oil, iron ores and gold) when brought for processing by industrial chemists and metallurgists to meet the requirements of the ultimate consumers. Each essay indicates by record of trade specifications what impurities the factories can tolerate, and details the more important purposes to which supplies of mineral products are directed. A good many of the essays were written, and published in a technical journal, when the author was Principal of the Mineral Resources Department of the Imperial Institute and Head of the Commodities Intelligence section of the Ministry of Economic Warfare. The information selected from official files is tersely put and as convenient for the geologist as for the chemist for whom the book is primarily designed.

Some forty chemical elements are considered, in alphabetic order, with minerals, soluble salts and earthy aggregates that have specific physical

properties, and are supplied in bulk to heavy chemical industries, intercalated. Each essay begins with a list of source minerals and a brief statement of their peculiarities, but says little about their mode of occurrence. Specifications and analyses of acceptable deliveries are included. Next follows a summary account of recent world production, but with few mine locations named. Such statistics, including quantities of exports and imports, and conditions of American stock-piling, can (for estimating the scale of profitable operations) save geological inquirers a lot of time. Then come outline accounts of mine extraction, separation of minerals from matrix, reduction of ores and subsequent chemical purification of products to the satisfaction of users. The specification of grades of raw material, related to the purposes to which they are applied, should be specially valuable for those geologists who have responsibilities for the development of new prospects. It is the user who determines purchases, and it is the chemists' business to get rid of impurities, but the geologist must recognize that difficulties to be overcome in processing are prime factors in determining the value of the mineral mined. This kind of information has rarely been made so conveniently accessible for geologists, and is a very welcome feature of the book.

The longest essay deals with titanium. It will be of interest to many that already in 1951, more than a million tons of ilmenite was used in pigment-making, and that " each Sabre jet fighter is now being made with 600 pounds of metallic titanium in its frame ". The importance of zirconium is similarly emphasized, more particularly the application of zircon and the oxide as super-refractories, while the metal zirconium is now being fabricated by the ton. Of beryllium, it is recorded that in 1951, 5,000 tons of beryl containing 5 per cent Be was concentrated and sold. Within the limits of security, the story of uranium and thorium minerals is faithfully presented, with an account of the latest pre-war methods of extraction of radium from pitchblende. There is also an adequate account of the extraction of the several rare-earth metals from monazite.

Among articles compiled about so many and diverse substances, it is not surprising that the authenticity of information is variable. The silicate minerals come off worst. It is surprising to read that in silica bricks, " small amounts of iron act as a binding agent and up to 3 per cent is not deleterious ". Also that " fireclay may be described as an amorphous plastic detrital material in which the percentages of iron oxide, lime, magnesia, and alkalies are sufficiently low to enable the material to withstand a temperature of 1580° C. without fusing ". On these and other matters concerning refractories, there is better information in the recently-published Jubilee Volume of the Ceramic Society. It is, however, good to have the chemist's admission that " In general the only satisfactory method of ascertaining whether fuller's earth from any particular locality is suitable for oil refining is to carry out practical tests with the oil in question under conditions of use ". In other articles the assessment of technical information quoted is similarly fair.

It is important that geologists should recognize that limitations are set upon the value of mineral raw materials by the costs of processing, and in this book the rhyme and reason of value of the several grades is clearly expressed. It is an expensive book, but it should be made available for consultation in all geological libraries. The bibliographies are well selected, and the index adequate.

W. G. F.

CLAY MINERALOGY. By RALPH E. GRIM. pp. xii + 384, 46 tables, 121 figs., appendix A-G tables. McGraw-Hill Book Co., New York, 1953. Price 64*s.* 6*d.*

This treatise covers in a thorough fashion the large field of clay mineralogy and sets out in a very readable form many topics originally scattered widely throughout the literature.

Gaps in information are stressed, the need for more research in some fields is made very obvious, and emphasis is laid upon this in the introductory chapter. Chapter 2 contains a good summary of the history of this rapidly expanding subject, while Chapter 3 is devoted to classification and nomenclature. The following chapter on structure is perhaps more difficult to follow for the reader unacquainted with structural data, but the excellent figures and line drawings are helpful. Chapter 5 contains X-ray diffraction results mainly taken from the Mineralogical Society of Great Britain Monographs on clay minerals. In this chapter there is a very lucid explanation of mixed-layer structures. Following this comes a section on shape and size of particles and data gleaned from electron microscopy are presented, the text being illustrated with many well produced photographs. Chapter 7 deals with ion exchange (both cationic and anionic) and the author stresses the value of such methods in evaluation of clay minerals and shows the importance of this neglected field. Chapter 8 discusses the clay-water system, the nature and configuration of adsorbed water, effects of cations on the inner-layer surfaces and variations in mechanical properties of clays with adsorbed water. This leads very naturally to dehydration and rehydration data, and emphasis is laid on differential thermal analysis, a field in which the author is a pioneer and acknowledged authority. This chapter contains some very interesting new data on high temperature reactions. Chapter 10 deals with organic complexes and this leads eventually to a discussion of staining techniques. Next follows a chapter on optical data including matter not normally dwelt upon, such as electrical field orientation, form birefringence, etc. Chapter 12 contains interesting miscellaneous methods of analysis including those, such as infra-red spectroscopy, which as yet are comparatively undeveloped. The final two chapters are devoted to origin and occurrence of clay minerals and contain a penetrating analysis of the known facts with the conclusions which may be drawn.

The book is liberally endowed with tables, figures, and numerous references. In this latter regard it is most unfortunate that much of the Russian literature was unavailable to the author.

There appears to be a misprint on p. 223, where the term " anhydrite " structure is used for what is obviously " anhydride " structure.

The book is most welcome and timely in this rapidly growing field, and is warmly recommended.

R. J. McL.

THE SOILS OF EUROPE. By W. L. KUBIËNA. English edition (printed in Spain). pp. 318, 26 plates (mainly in colour), 11 figs. Thomas Murby and Co., London, 1953. Price 75*s*.

Professor Kubiëna's great contribution to pedology has been the development of micro-methods for the examination of humus forms and soil fabrics. In the present work he has used these methods, coupled with his enormous experience of field observation, to present a very complete description and classification of European soils.

His book can be recommended, not only to pedologists as a most important contribution to soil systematics, but also to others, such as ecologists and geologists, who may be interested in particular soil types, and wish to know how these fit into the wider pattern. The book is based on a series of keys which allow easy and precise identification of humus and soil types, and contains a useful glossary and bibliography. The more important profiles are illustrated by an excellent series of water colours, which, although they sometimes overemphasize the sharpness of horizon boundaries, show up essential characteristics in a very satisfactory manner.

It is unfortunate, however, that this English edition of a book of such outstanding value should be marred by an altogether unreasonable number of errors in the text.

R. W. P.